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A

INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1893.

PARTS 1–2.

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3/7/94

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PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77.

John Robinson, 1878–79.

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86.

Sir Edward H. Carbutt, Bart., 1887–88.

Charles Cochrane, 1889.

Joseph Tomlinson, 1890–91.

Institution of Mechanical Engineers.

OFFICERS.

1893.

PRESIDENT.

William Anderson, D.C.L., F.R.S.,	Woolwich.

PAST-PRESIDENTS.

The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Thomas Hawksley, F.R.S.,	London.
Jeremiah Head,	Middlesbrough.
John Ramsbottom,	Alderley Edge.
John Robinson,	Leek.
Joseph Tomlinson,	London.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir James N. Douglass, F.R.S.,	London.
Sir Douglas Galton, K.C.B., D.C.L., F.R.S.,	London.
Alexander B. W. Kennedy, F.R.S.,	London.
Edward B. Marten,	Stourbridge.
Sir James Ramsden,	Barrow-in-Furness.
E. Windsor Richards,	Low Moor.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
William Dean,	Swindon.
John Hopkinson, Jun., D.Sc., F.R.S.,	London.
Samuel W. Johnson,	Derby.
Arthur Keen,	Birmingham.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Francis C. Marshall,	Newcastle-on-Tyne.
Henry D. Marshall,	Gainsborough.
Edward P. Martin,	Dowlais.
William H. Maw,	London.
James Platt,	Gloucester.
T. Hurry Riches,	Cardiff.
William H. White, C.B., LL.D., F.R.S.,	London.
J. Hartley Wicksteed,	Leeds.

TREASURER.

Harry Lee Millar.

SECRETARY.

Alfred Bache,

Institution of Mechanical Engineers, 19 *Victoria Street, Westminster, S.W.*

[Telegraphic address:—*Mech, London.* Telephone: 3264.]

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

FEBRUARY 1893.

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

NOW THEREFORE IT IS HEREBY AGREED as follows:—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1893.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s*. additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10*s.*, and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s.* additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the

Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being years of age, and desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this day of

Members or Associate Members.

FORM B.

Mr. born on being desirous of admission into the Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this day of

Members or Associate Members.

FORM C.

If elected an of the Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement and paying the entrance fee and annual subscription in conformity with the By-laws.

Witness my hand, this day of

FORM D.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of of the Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of the Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

Institution of Mechanical Engineers.

PROCEEDINGS.

FEBRUARY 1893.

The FORTY-SIXTH ANNUAL GENERAL MEETING of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 2nd February 1893, at Half-past Seven o'clock p.m.; Dr. WILLIAM ANDERSON, F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirteen candidates were found to be duly elected:—

MEMBERS.

HENRY AINLEY,	Oldham.
THOMAS HENRY CRIPPIN,	Manchester.
CHARLES HERBERT,	London.
GEORGE HENRY HERBERT,	Manchester.
ARTHUR WILLIAM JAMES,	Calcutta.
HENRY HORWOOD JENNINS,	Leeds.
JOHN WARDEN KINGHORN,	Hong Kong.
JAMES LAWRIE,.	Penang.
WILLIAM HENRY MASSEY,	London.
RICHARD EDWARD LLOYD MAUNSELL,	Fleetwood.
FREDERICK HANDEL MILLINGTON,	Thetford.
ALFRED SAXON,	Manchester.
GEORGE RICHARD STEWARD,	London.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1893.

At this Forty-Sixth Annual General Meeting of the Institution, the Council have the pleasure of presenting the following as their Annual Report to the Members respecting the proceedings of the Institution during the past year.

At the end of last year the number of names in all classes on the roll of the Institution was 2147, as compared with 2077 at the end of the previous year, showing a net gain of 70. During 1892 there were added to the register 148 names; against which the loss by decease was 25, and by resignation or removal 53.

The additions to the list of Members include, as the President had the gratification of announcing at the Spring Meeting, the name of His Royal Highness the Duke of Cambridge, whom the Council had the honour of electing an Honorary Life Member of the Institution.

During the past year a baronetcy has been conferred by Her Majesty upon Mr. Edward H. Carbutt, Past-President, and a knighthood upon Mr. William Renny Watson, Member of the Institution.

The following eight Transferences of Graduates to the class of Members have been made by the Council in 1892:—

Edward William Anderson,	Erith.
Percy Vavasseur Appleby,	London.
Albert Reuben Atkey,	Nottingham.
Sidney Boulding,	London.
Thomas Johnstone Bourne,	Woodbridge.
Hugh Myddleton Butler,	Leeds.
Percy Grant,	Buenos Aires.
Charles Liddell Simpson,	London.

The following thirty Deceases of Members of the Institution have occurred during the past year:—

William Bertram,	Edinburgh.
Richard Birtwistle,	Manchester.
Sir James Brunlees, F.R.S.E.,	London.
Alfred Alphonse Rouff Clinkskill (Graduate),	Glasgow.
Thomas Edwin Craven,	Leeds.
Edward Frederic Crippin,	Wigan.
John Piggin Fearfield,	Nottingham.
William Firth,	Leeds.
Richard Henesey,	Bombay.
John Herbert Holroyd,	Gadag, India.
Matthew Murray Jackson,	Brighton.
Amandus Edmund Keydell,	Dundee.
Alexander Carnegie Kirk, LL.D.,	Glasgow.
Hermann Ludwig Lange,	Manchester.
Alexander Lavalley,	Paris.
Henry John Marten,	Wolverhampton.
John William Miers,	London.
Alfred Perry,	Birmingham.
George Henry Poke (deceased 1891),	Bombay.
William Richardson,	Oldham.
George John Miller Ridehalgh (Associate),	Ulverston.
James Salkeld Robinson,	Rochdale.
George Ryder,	Bolton.
Henry Sandham (Associate),	London.
Christopher J. Schofield (Associate),	Manchester.
Dr. Ernst Werner von Siemens,	Berlin.
James Taylor,	Oldham.
John Varley (Associate),	Leeds.
William Hugill Walker,	Sheffield.
Peter William Willans,	Thames Ditton.

Of these Mr. Richardson was a Member of Council from 1877 to 1884, having been a Member of the Institution from 1859.

The following twenty-seven gentlemen have ceased to be Members of the Institution during the past year:—

Francis Louis Adcock,	Kimberley.
Thomas Arthur Arrol,	Glasgow.
Joseph Harrison Ashby (Graduate),	Cardiff.
John Cotton,	Southport.

George Crampton,	London.
Alfred Herbert Davies,	Nottingham.
John Donnelly,	London.
Richard Kendall Evans,	Nottingham.
William Bromley Featherstone,	London.
Martin William Brown Ffolkes (Graduate),	London.
Harry Jones Harman,	London.
William Hooton,	Nottingham.
Frank Edward Hoyle,	Liverpool.
Frederic Kershaw,	Buenos Aires.
Robert Lundon,	Melbourne.
Thomas Maughan,	Cramlington.
Alfred Timothy O'Sullivan (Associate),	Swansea.
Vernon Petherick,	Sydney.
Julius Frederick Moore Pollock,	Leeds.
Thomas Powell,	Rouen.
David Codrington Selman,	Sydney.
Samuel Lord Sharrock,	Sydney.
Robert John Walker,	Birkenhead.
James George Whitehead,	Peru.
Henry Wilson,	South Shields.
Charles Smith Worssam,	London.
George Friedrich Zimmer,	London.

In addition to these there have been twenty-six Resignations of membership.

The Accounts for the year ending 31 December 1892 are now submitted to the Members (*see* pages 12–15), after having been passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £7,192 2*s.* 5*d.*, while the expenditure, actual and estimated, was £4,987 18*s.* 11*d.*, leaving a balance of receipts over expenditure of £2,204 3*s.* 6*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £38,918 13*s.* 7*d.*; and allowing £600 for accounts owing but not yet rendered, the capital of the Institution amounts to £38,318 13*s.* 7*d.*, of which the greater part, as seen from the balance sheet, is invested in Railway Debenture Stocks, registered in the name of the Institution. The certificates of the whole of the securities have been duly audited by the Finance Committee and the auditor.

The Certificate of Membership, which has been completed in conformity with the accepted design, is in readiness for issue to those of the Members who may wish to make application for it in accordance with the By-laws. To those who have done so, it has been issued already.

With the aim of keeping the professional status of Membership in the Institution as high as possible, and also with a view to defining more clearly the qualifications for the several classes, the Council have revised the existing regulations. They propose the establishment of an additional class, to be called Associate Members, intermediate between the present classes of Members and Graduates. Various other recommendations connected with this proposal were announced at the last General Meeting, at which formal notice was given for bringing these forward at the present Meeting. As the recommendations of the Council involve alterations in the Articles of Association as well as in the By-laws, and as the Articles have remained unchanged since the incorporation of the Institution in 1878 and contain certain provisions which applied solely to that time and which have now become obsolete, the Council desire to take advantage of the present occasion of amending the Articles and By-laws, by the omission of all obsolete provisions. The complete Articles and By-laws thus amended have been duly circulated among the Members with a view to their discussion at the present Meeting.

In the same connection the Council take the opportunity of reminding the Members that the abbreviated designation provided for this Institution in the By-laws was intentionally settled to be I. Mech. E., for the express purpose of rendering the distinction sufficiently clear from the Institutions of Marine and of Mining Engineers, whose members are found to be making use of the initials

I.M.E. for designating their respective societies. If the Members of this Institution will kindly be careful to adopt the definite abbreviation Mech. instead of the ambiguous initial M., all doubt as to the real membership will be removed so far as this Institution is concerned, and the full value of the corresponding professional status will be conveyed in the abbreviation.

The Research Committee on Marine-Engine Trials, having presented at the Spring Meeting their last report, upon the trial of the engines of the Belgian mail steamer "Ville de Douvres," are led by their chairman, Professor Kennedy, to entertain the hope that some competent engineer may find leisure to prepare a concise summary and review of the whole series of trials which have so far taken place: in order to facilitate further discussion of the materials which have been collected with so much labour and expense.

The Research Committee on the Value of the Steam-Jacket presented at the Autumn Meeting their second report, containing several important experiments carried out on a practical scale with a special view to this research; and the chairman, Mr. Henry Davey, was able to announce further experiments already arranged to be carried out or still in contemplation, which will form the subject of a subsequent report, and will render it easier for some general conclusions to be drawn.

The Alloys Research Committee, of which the President is the chairman, are looking forwards to receiving a further report from Professor Roberts-Austen, who has been continuously extending his investigations.

In the President's Address at the Spring Meeting he suggested, as a sphere of usefulness wherein good service might be done, the compilation of a Reference Index of Engineering Literature at home and abroad. The Council have therefore under consideration the method of carrying out an object which they regard as likely to prove of much utility to the profession, and to which they think some contribution from the funds of the Institution may reasonably be devoted, if sufficient co-operation on the part of other societies can be secured for its accomplishment.

The additions that have been presented to the Library of the Institution during the past year are enumerated in pages 16–24. For these contributions the Council here record their thanks to the several Donors. Members are invited to present original pamphlets on engineering subjects and records of experimental research, and other works valuable for reference, which are always welcome for permanent preservation in the Library. The Council desire also to remind the Members of the fact that they will be glad to receive unpublished records of mechanical experiments, or such other communications on engineering subjects as may contain valuable information for the profession, even though not taking the form of papers for reading and discussion at the meetings of the Institution; in order that any of these which they may consider suitable to be so made known may be published in the Proceedings for the benefit of the Institution. They hope that much valuable information and many practical experiments and important data may in this way be put on record, which at present are perhaps lost to the engineering world.

The General Meetings in 1892 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting in Portsmouth; and the Autumn Meeting in London. Altogether eight sittings were occupied in the reading and discussion of the following Papers, which are published in the Proceedings:—

Notes on Mechanical Features of the Liverpool Water Works, and on the supply of Power by pressure from the public mains, and by other means; by Mr. Joseph Parry.

On the Disposal and Utilization of Blast-Furnace Slag; by Mr. William Hawdon.

Address by the President, Dr. William Anderson, F.R.S.

Research Committee on Marine-Engine Trials: Report upon Trial of the Steamer "Ville de Douvres"; by Professor Alexander B. W. Kennedy, F.R.S., Chairman.

On Condensation in Steam-Engine Cylinders during Admission; by Lt.-Colonel Thomas English.

On Shipbuilding in Portsmouth Dockyard; by Mr. William H. White, C.B., F.R.S.

On the Applications of Electricity in the Royal Dockyards and Navy; by Mr. Henry E. Deadman.

Description of the Lifting and Hauling Appliances in Portsmouth Dockyard; by Mr. John T. Corner, R.N.

Description of the new Royal Pier at Southampton; by James Lemon, Esq., J.P., Mayor.

Description of the Portsmouth Sewage Outfall Works; by Sir Frederick Bramwell, Bart., D.C.L., LL.D., F.R.S., Past-President.

Description of the new Floating Bridge between Portsmouth and Gosport; by Mr. H. Graham Harris.

Description of the Southampton Sewage Precipitation Works and Refuse Destructor; by Mr. William B. G. Bennett.

Second Report of the Research Committee on the Value of the Steam-Jacket. Mr. Henry Davey, Chairman.

Experiments on the Arrangement of the Surface of a Screw-Propeller; by Mr. William George Walker.

The attendances during 1892 were as follows:—at the Annual General Meeting 99 Members and 55 Visitors; at the Spring Meeting 119 Members and 82 Visitors; at the Summer Meeting 187 Members and 107 Visitors; and at the Autumn Meeting 97 Members and 55 Visitors.

The Summer Meeting was held for the first time in Portsmouth, where special arrangements were made by permission of the Lords of the Admiralty for visiting the Royal Dockyard, in connection with which three papers were prepared for the occasion, one by Mr. White, Member of Council, Director of Naval Construction and Assistant Controller of the Navy, and two others through his kindness by the Chief Constructor and the Chief Engineer of Portsmouth Dockyard. The Town Hall was placed at the disposal of the Institution for the Meeting, and for all connected purposes, by the kindness of the Mayor, T. Scott Foster, Esq., J.P.; and the various arrangements were matured with the obliging aid of the Borough Engineer, Mr. Philip Murch, as Honorary Secretary. Visits were also paid to the Royal Clarence Victualling Yard, Gosport; to Fort Cumberland, where Major-General Geary was so good as to fire a few rounds from a 6-inch disappearing breech-loading gun, mounted on a hydro-pneumatic carriage; to the Eastney Sewage Works; and to the site of the new Floating Bridge between Portsmouth and Gosport. Of the two latter, descriptions were given to the Meeting by Sir Frederick Bramwell, Bart., Past-President, and Mr. H. Graham Harris.

A day's excursion was made to Southampton, on the kind invitation of the Mayor, James Lemon, Esq., J.P., who received the Members on arrival upon the new Royal Pier just completed from his designs, of which he also furnished a description to the Meeting. Visits were paid to the Southampton Docks, the Ordnance Survey Office, the Southampton Water Works at Otterbourne, the London and South Western Railway Carriage and Wagon Works at Eastleigh, and a number of Engineering and Yacht Building Works, as well as the Sewage Precipitation Works and Refuse Destructor, of which last a description was given to the Meeting by Mr. William B. G. Bennett, the Borough Engineer and Surveyor. The various arrangements were matured with the obliging aid of Mr. George C. Day, as Honorary Secretary.

A voyage round the Isle of Wight, on the invitation of the Joint Railway Companies, and a visit to the London Brighton and South Coast Railway Locomotive and Carriage Works, Brighton, formed an agreeable termination to a Summer Meeting, at which the attendance of the Members, though less than in the previous year, cannot be regarded as otherwise than good, when it is borne in mind how great an inroad had just been made into their time and their ordinary engagements by the occurrence of a general parliamentary election only a few weeks previously. A feature which has been noted with much gratification by the Council and by the Members attending this Meeting is that the burden of the necessary arrangements was distributed among the Members for whose benefit they were made: thereby showing for the first time how the Members may be enabled to enjoy the advantage of visiting various localities, free from all misgivings lest any risk should be run of their visit assuming in any degree the aspect of a visitation. The same considerations clearly enlarge the range of localities in which future Meetings of the Institution may advantageously be held.

For the present year the Council are indebted to the kindness of Mr. Jeremiah Head, Past-President, for taking the preliminary steps whereby they are now enabled to announce that the Summer Meeting will be held in Middlesbrough in the first week of August. Assurances have been received that opportunities will be given for visiting most of the important Works in the Cleveland district, which has experienced so great an extension of engineering interests during the interval of twenty-two years that has elapsed since the former visit of the Institution in 1871.

In view of the possible attendance of Members of this Institution at the Columbian Exposition to be held at Chicago this year, the Council have the pleasure of announcing that a joint letter has been received from four committees of the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and the American Institute of Electrical Engineers, assuring the visitors of the hearty welcome which awaits them on their arrival in New York from their professional brethren, and informing them that the homes of the several Societies will be open to them, and offering to facilitate the objects of their visit. An invitation has also been received to participate in the Engineering Congress intended to be held in Chicago under the auspices of the Columbian Exposition; and to make use of the Engineering Headquarters which will be maintained in Chicago during the period of the Exposition by the principal American and Canadian Societies of Engineers.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1892	804	14	8			
,, Reprinting former Proceedings	61	3	0			
	865	17	8			
Less Authors' Copies of Papers, repaid	7	7	0	858	10	8
,, Stationery and General Printing				201	1	11
,, Certificate of Membership				46	4	5
,, Binding				38	12	8
,, Rent				710	0	0
,, Salaries and Wages				2,013	15	0
,, Coal, Firewood, and Gas				35	17	0
,, Fittings and Repairs				43	4	5
,, Postages, Telegrams, and Telephone				274	0	6
,, Insurance				7	0	6
,, Petty Expenses				44	19	4
,, Meeting Expenses—						
Printing	190	6	6			
Reporting	43	4	8			
Diagrams, Screen, &c.	89	9	7			
Travelling and Incidental Expenses	107	14	10	430	15	7
,, Dinner Guests				59	17	4
,, Research				202	10	9
,, Books purchased				21	8	10
				4,987	18	11
Accounts owing, not yet rendered, say	600	0	0			
Less Reserve in previous year for accounts since paid	600	0	0	0	0	0
Balance, being excess of Receipts over Expenditure, carried down				2,204	3	6
				£7,192	2	5

	£	s.	d.	£	s.	d.
To Investments—						
£974 *Great Eastern Railway* 4% *Debenture Stock*	1,279	18	2			
£1,000 *Taff Vale* ,, 3% ,, ,,	969	19	0	2,249	17	2
Cash Balance 31st December 1892				2,964	13	7
				£5,214	10	9

FOR THE YEAR ENDING 31st DECEMBER 1892. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
108 *New Members at £2*	216	0	0			
12 *New Associates at £2*	24	0	0			
24 *New Graduates at £1*	24	0	0			
8 *Graduates transferred to Members at £1*	8	0	0	272	0	0
„ Subscriptions for 1892—						
1667 *Members at £3*	5,001	0	0			
67 *Associates at £3*	201	0	0			
143 *Graduates at £2*	286	0	0			
8 *Graduates transferred to Members at £1*	8	0	0	5,496	0	0
„ Subscriptions in arrear—						
76 *Members at £3*	228	0	0			
2 *Associates at £3*	6	0	0			
11 *Graduates at £2*	22	0	0	256	0	0
„ Subscriptions in advance—						
24 *Members at £3*	72	0	0			
5 *Graduates at £2*	10	0	0	82	0	0
„ Interest—						
From Investments	722	11	9			
From Whitworth Bequest	234	2	6			
From Bank	35	16	10	992	11	1
„ Reports of Proceedings—						
Extra Copies sold				93	11	4
				£7,192	2	5

	£	s.	d.
By Balance brought down	2,204	3	6
By Life Composition, 1 Member	50	0	0
Cash Balance 31st December 1891	2,960	7	3
	£5,214	10	9

Dr. BALANCE SHEET

	£	s.	d.
To Sundry Creditors—			
Accounts owing, not yet rendered, say	600	0	0
Capital of the Institution at this date	38,318	13	7
	£38,918	13	7

Signed by the following members of the Finance Committee :—

WILLIAM ANDERSON,
ALEX. B. W. KENNEDY, | JOHN G. MAIR-RUMLEY,
JOHN HOPKINSON, Jun., | WILLIAM H. MAW.

AS AT 31ST DECEMBER 1892.

Cr.

	£	s.	d.	£	s.	d.	£	s.	d.
By Cash—*In Union Bank, on Deposit*				2,100	0	0			
" " " *on Current account* . .				364	13	7			
In Imperial Bank . . .	486	2	9						
In hand	13	17	3	500	0	0	2,964	13	7
" Investments—(*cost* £22,537 2*s*. 11*d*.)									
£									
3,178 *London and North Western Ry.* 4% *Debenture Stock*									
2,200 *North Eastern* " " " "									
1,800 *Great Western* " " " "									
2,244 *Great Eastern* " " " "									
2,755 *Metropolitan* " " " "									
2,325 " " 3½% " "									
1,000 *Aire and Calder Navigation* " " "									
3,288 *Midland Railway* 3% " "									
2,450 *Taff Vale* " " " "									
700 *Sir J. Whitworth and Co., Ld.* 5% " "									
Two hundred £10 shares Sir J. Whitworth and Co., Ld.									
The Market Value of these investments at 31st Dec. 1892 was about . .							29,491	0	0
" Subscriptions in Arrear, probable value							260	0	0
" Office Furniture and Fittings							343	0	0
" Library							1,240	0	0
" Proceedings, back numbers at cost							4,520	0	0
" Drawings, Engravings, Models, Specimens, and Sculpture .							100	0	0
							£38,918	13	7

Audited and Certified by

ROBERT A. McLEAN, Chartered Accountant,
1 Queen Victoria Street, London, E.C.

LIST OF DONATIONS TO LIBRARY.

Gas Engineer's Pocket Almanack, 1892; from Messrs. William Sugg and Co.

Ninth Report on the Working of the Boiler Explosions Act, 1882 and 1890, during the year 1890–91; from the Board of Trade.

Foundations, by H. G. Foster Barham; from the author.

Annual Report of the Chief of the Bureau of Steam Engineering, United States Navy Department, 1891; from the Bureau.

Sanitation as applied to our Homes, by Percy C. Gilchrist and others; from Mr. Percy C. Gilchrist.

Messrs. Hayward Brothers and Eckstein's Diary, 1892; from the publishers.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 Dec. 1891 and to 30 June 1892; from the Registrar.

Heating and Welding by the Electric Arc; from Mr. Samuel MacCarthy.

Description and comparison of the methods of Electric Lighting at present in use in London, by Professor Alex. B. W. Kennedy; from the author.

Guide Book to Technical Literature; from Mr. James Armer.

Notes on the Construction of Ordnance; from the Ordnance Office, Washington, United States.

Persia, its Language and Literature, by Major-General Sir Frederic Goldsmid, K.C.S.I., C.B.; from the Imperial Institute.

Technical Education, by C. M. Percy; from the author.

Third Annual Report of the De Beers Consolidated Mines for the year ending 31 March 1891; from Mr. Thomas Quentrall.

Album of Statistical Tables and Diagrams of Locomotive Working on the Grazi and Tsaritsin Railway; from Mr. Thomas Urquhart.

Cross-River Communication west of Glasgow Bridge; from Messrs. W. and A. Wilson.

Railway Connections in the east end of Glasgow from Bridgeton Cross; from Messrs. W. and A. Wilson.

Annual Report of the United States Chief of Ordnance, 1891; from the Ordnance Office, Washington, United States.

Development of the American Rail and Track, as illustrated by the collection in the United States National Museum; from the Smithsonian Institution.

Illustrated price list of Wrought-Iron Pulleys, Shafting, and Friction Couplings; from Messrs. J. Bagshaw and Sons.

Proposals for Utilizing Water Power in Southern India, by Alfred Chatterton; from the author.

Compte Rendu des Séances du 14^{me} Congrès des Ingénieurs en Chef des Associations de Propriétaires d'Appareils à Vapeur, Marseilles, 1890; from the Association Belge pour la Surveillance des Chaudières à Vapeur.

Lockwood's Builder's and Contractor's price book, 1892; from Messrs. Crosby Lockwood and Son.

Miners' and Metallurgists' Pocket-Book, by F. D. Power; from Messrs. Crosby Lockwood and Son.

Eight Hours' Day, by Robert A. Hadfield; from the author.

Illustrated catalogue of the Compactum specialities; from Mr. John Kirkaldy.

The following from Mr. W. Cooper:—Life of Telford; Description of the Construction of the Edystone Lighthouse, by John Smeaton; Letters and important documents relative to the Edystone Lighthouse, by R. H. Weston; Britannia and Conway Tubular Bridges, Plates, by Edwin Clark.

Tests of Metals &c. at Watertown Arsenal, Massachusetts, 1890; from the Ordnance Office, Washington, United States.

Welsh Water scheme not for Birmingham; from Mr. Samuel Lloyd.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1892; from the Inspector-General of Chinese Customs.

Report of the Kew Observatory Committee, 1891; from the Committee.

The following from Mons. H. Le Chatelier:—Mesure des hautes Températures, réponse à Mons. H. Becquerel; Mesure optique des Températures élevées; Borates métalliques; Théorie du Regel; Températures développées dans les Foyers industriels.

St. Pancras Electric Lighting, by Professor Henry Robinson; from the author.

Detachable Ram, by Lieut. W. H. Jaques; from the author.

Fourth Annual Report of the Robinson Gold Mining Co., 1891; from Mr. F. H. Spencer.

Catalogue of the Reference Department of the Liverpool Free Public Library, Part 1, 1850–70, and Part 3, 1881–91; from the Committee.

Report to the Governors of the City and Guilds of London Institute, April 1892; from the Institute.

Students' Cotton Spinning, by Joseph Nasmith; from the author.

Index to the literature of Thermodynamics, by Alfred Tuckerman; from the Smithsonian Institution.

Secondary Batteries, by J. T. Niblett; from the author.

Steam Boilers, their defects, management, and construction, by R. D. Munro; from the author.

Four Diagrams and one Map illustrating the Mean Annual Rainfall of Queensland; from Mr. John B. Henderson.

Nouveau système de Frein Continu, by L. Soulerin; from the author.

Freins Soulerin, four vols., by L. Soulerin; from the author.

Chicago Exhibition 1893: handbook of regulations and general information; from the Royal Commission.

Specifications and contract for High-service Pumping Engine No. 3, Boston Water Works, United States; from Mr. Erasmus D. Leavitt.

Wasserröhrenkessel, by Fritz Krauss; from the author.

Report to the Council of the Neapolitan Steam Boiler Association, by Francesco Sinigaglia; from the Association.

Reports of the Tenth Census of the United States; from Mr. George R. Dunell.

Use of Belting for the Transmission of Power, by John H. Cooper; from the author.

Report on the Compound Locomotive of the Rhode Island Locomotive Works; from Mr. John H. Cooper.

Description of a Machine for finding the numerical Roots of Equations and tracing a variety of useful Curves, by F. Bashforth; from the author.

Memoirs of distinguished Men of Science, together with framed Engraving and Key thereto; from Mr. H. S. Cotton.

Rôle de l'Eau dans les Cylindres à Vapeur, by L. Anspach; from the author.

Spons' Engineers' and Contractors' illustrated book of prices 1892-93; from the publishers.

Natural process of Dissolution for Smoke and Fogs, by Colonel Dulier; from the author.

Mean or Average Annual Rainfall, and the fluctuations to which it is subject, by A. R. Binnie; from the author.

Blast-Furnace Plant, Equipment and Design, by Herbert Pilkington; from the author.

Re-determination of the Mass of a cubic inch of Distilled Water, by H. J. Chaney; from the author.

Presidential Address to the Society of Engineers, 1892, by J. W. Wilson, Jun.; from the author.

Railway Statistics (two charts); from Mr. M. R. Jefferds.

Presidential Address to the Incorporated Gas Institute, 1892, by W. A. Valon; from the author.

Scientific and Technical Papers of Dr. Werner von Siemens, vol. 1; from Mr Alexander Siemens.

Metropolis Water Supply, 1892, by Messrs. Hassard and Tyrrell; from the authors.

Nouvelle Locomotive Compound à quatre cylindres et à grande vitesse du chemin de fer du Nord, by Du Bousquet; from the author.

Extracts from the Portsmouth Records, by Robert East; from the Mayor of Portsmouth, T. Scott Foster, Esq., J.P.

General Directory and Railway List of Locomotive and Carriage Superintendents for India; from the Secretary.

Screws and Screw-Making; from the Britannia Co.

Imperial Institute Year-Book, 1892; from the Institute.

Contribution à l'étude des Combustibles, by P. Mahler; from the author.

Register of the Institute of Chemistry of Great Britain and Ireland, 1892; from the Institute.

Central-Station Management and Finance, by H. A. Foster; from Mr. Druitt Halpin.

Gerhard Moritz Roentgen der Erfinder der Mehrfach-Expansions-Dampfmaschine, by E. Brückmann; from the author.

Mr. Murdock's Letter on the Gas Company's Bill; from Mr. Richard B. Prosser.

Catalogue of Tubes and Fittings, 1892, by Messrs. Lloyd and Lloyd; from Mr. Samuel MacCarthy.

Illustrated catalogue of Electrical Apparatus; from Messrs. Dorman and Smith.

Diamond Mines of South Africa, by Theodore Reunert; from the author.

Engineering Telegraph Code, by A. H. Blackburn and James Stevens; from Mr. James Stevens.

Stevenson's Bell Rock Lighthouse; from Mr. H. S. Cotton.

Appareils accessoires concernant la production et l'emploi de la Vapeur, by Gaston Novince; from the author.

The following official publications from the Government of New South Wales:—Maps to accompany Progress Report of extension of Railway into the City and the North Shore Bridge connection; Report on Dredging Operations; Report on Artesian Boring; Reports of Royal Commissions of enquiry into the alleged defectiveness and unsuitability of the Baldwin Locomotives, 1892, and into the charges against Mr. E. M. G. Eddy, Chief Commissioner of Railways, 1892.

The following publications from the United States Geological Survey:—Tenth Annual Report of the United States Geological Survey, 1888–89, by J. W. Powell; Bulletins of the United States Geological Survey, Nos. 62, 65, and 67–81; Mineral Resources of the United States, 1889 and 1890.

Present position of Roller Flour Milling, by Henry Simon; from the author.

Notes on the Construction of Cranes and Lifting Machinery, by E. C. R. Marks; from the author.

Report upon the past History, present State, and further Improvements of the Navigation of the River Severn, by Henry J. Marten; from the author.

Hydraulic Machinery, by G. C. Marks; from the author.

Canal Maritime de Manchester, by de Pulligny; from the author.

Illustrated catalogue of the Ingersoll-Sergeant Drill Co.; from the Company.

History of the Baldwin Locomotive Works from 1831–1881; from Messrs. Burnham, Williams and Co.

Cremation. by Henry Simon; from the author.

Transatlantic Lines and Steamships, by A. J. Maginnis; from the author.

Log of the Savannah, by J. E. Watkins; from the Smithsonian Institution.

"Practical Engineer" Pocket-Book and Diary, 1893; from the editor.

Domestic Electric Lighting, by E. C. de Segundo; from the author.

Historique de l'Application de la Vapeur Surchauffée, by N. J. Raffard; from the author.

Calendar 1891–92 of University College of South Wales and Monmouthshire; from the College.

Cornell University, Ithaca, New York, Register 1891–92 (2nd edition); from the University.

Calendars for 1892–93 from the following Colleges:—Royal Technical High School, Berlin; Mason Science College, Birmingham; University College, Bristol; Glasgow and West of Scotland Technical College, Glasgow; Yorkshire College, Leeds; City of London College; King's College, London; Sheffield Technical School, and Firth College, Sheffield.

Subject-Matter Indexes of accepted complete Specifications of Inventions for 1884–85 and 1887–90; from the Patent Office.

Alphabetical Indexes of patentees and applicants for Patents of Invention for 1884–91; from the Patent Office.

Indices to Dr. James Henry's Aeneidea; from the Trustees.

Manufacture of Oxygen Gas, by Ferdinand Fanta; from Professor Watson Smith.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Report on Herreshoff system of Motive Machinery as applied to the steam yacht "Leila"; from Mr. George R. Dunell.

Ancien projet de Locomotive Électrique à grande vitesse &c., by N. J. Raffard; from the author.

Spons' Engineers' and Contractors' Diary and Reference Book, 1893; from the publishers.

Report of the Chief of the United States Bureau of Ordnance, 1892; from the United States Navy Department.

Annual Report of the Secretary of the United States Navy, 1892; from the United States Navy Department.

Bericht über die Aufstellung von Typen für Walz-Eisen, edited by Johann Buberl; from the Engineers' and Architects' Society of Austria.

The following Publications from the respective Societies and Authorities :—

Reports of the Academy of Science, France.
Annales des Ponts et Chaussées, Paris.
Proceedings of the French Institution of Civil Engineers.
Journal of the French Society for the Encouragement of National Industry.
Reports of the French Association for the Advancement of Science, 1890 and 1891.
Annales des Mines.
Annales du Conservatoire des Arts et Métiers.
Journal of the Marseilles Scientific and Industrial Society.
Proceedings of the Industrial Society of St. Quentin et de l'Aisne.
Proceedings of the Industrial Society of the North of France.
Proceedings of the Industrial Society of Rouen.
Proceedings of the Industrial Society of Mulhouse.
Annals of the Association of Engineers of Ghent.
Proceedings of the Society of German Engineers.
Reports of the Royal Academy of Science, Belgium.
Reports of the Royal Institute of Engineers, Holland.
Proceedings of the Engineers' and Architects' Society of Canton Vaud.
Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Engineers' and Architects' Society of Prague.
Proceedings of the Architects' and Engineers' Society of Hannover.
Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Russian Imperial Institute of Engineers.
Proceedings of the Swedish Technical Society.
Journal of the Norwegian Technical Society.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Report of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
United States Patent Office Gazette.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Committee of Locomotive and Carriage Superintendents for India.
Proceedings of the Engineering Association of New South Wales.
Proceedings of the Institution of Civil Engineers.

Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Chesterfield and Midland Counties Institution of Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Proceedings of the South Staffordshire Institute of Iron and Steel Works Managers.
Proceedings of the Royal Society of London.
Proceedings of the Royal Society of Edinburgh.
Proceedings of the Royal Institution of Great Britain.
Transactions and Professional Notes of the Surveyors' Institution.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Journal of the Royal Agricultural Society of England.
Journal of the Royal Statistical Society.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions and Journal of the Royal Institute of British Architects.
Transactions of the Incorporated Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.
Transactions of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions and Proceedings of the Royal Irish Academy.
Transactions and Proceedings of the Royal Dublin Society.
Transactions of the Institute of Marine Engineers.
Journal of the Liverpool Polytechnic Society.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Proceedings of the Society of Architects.
Transactions of the Manchester Association of Engineers.

Transactions of the Junior Engineering Society.

Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.

Records of Boiler Explosions in 1890, and bound vol. 2; from Mr. Edward B. Marten.

Report of the National Boiler Insurance Company; from Mr. Henry Hiller.

Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.

Report of the London Association of Foremen Engineers and Draughtsmen.

Ninth Annual Report of the Barrow-in-Furness Free Public Library.

Twenty-second Annual Report of the Bradford Free Public Libraries.

Thirty-ninth Annual Report of the Liverpool Free Public Library.

Fortieth Annual Report of the Manchester Public Free Libraries.

Ninth, Tenth, and Eleventh Annual Reports of the Newcastle-on-Tyne Public Libraries.

Catalogue of Additions to the Radcliffe Library, Oxford, during 1891.

The following Periodicals from the respective Editors:—

Revue générale des Chemins de fer.
Revue universelle des Mines.
Revue industrielle.
Stahl und Eisen.
Der Civil-Ingenieur.
Glaser's Annalen.
Giornale del Genio Civile.
Ingeniero y Ferretero Español y Sud Americano.
The American Manufacturer.
The Engineering and Mining Journal.
The National Car and Locomotive Builder.
The Railroad and Engineering Journal.
The Railway Master Mechanic.
The Indian Engineer.
The Engineer.
Engineering.
The Railway Engineer.
The Marine Engineer.
Iron.
The Iron and Coal Trades Review.
Ryland's Iron Trade Circular.
The Ironmonger.
Ironmongery.
The Mechanical World.
The Mining Journal.
The Colliery Guardian.
The Machinery Market.
The Builder.
The Electrician.
The Electrical Review.
The Chamber of Commerce Journal (from Mr. Henry Chapman).
The Contract Journal.
The Plumber and Decorator.
The Shipping World.
The Steamship.

The Fireman.
Industries.
Invention.
The Practical Engineer.
Electrical Plant.
Hardware Trade Journal.
The Railway Review.
Phillips' Monthly Machinery Register.
The Engineering Review.
Canadian Mining Review.
Cassier's Magazine.
The Surveyor.
Transport.
Electricity.
The Keyboard.

The President said that, in connection with the Engineering Congress to be held in Chicago under the auspices of the Columbian Exposition, to which the attention of the Members had been drawn in the Report of the Council, a letter had also been received from Mr. James Dredge, announcing his appointment as Honorary President of the Congress, and obligingly offering his assistance to any Members who might contemplate taking part in the conferences. Although the Council did not think that the Institution as a body could undertake anything in connection either with the Congress or with the Exposition, he was sure there would be some of the Members who would be glad to avail themselves individually of so welcome an offer; and he hoped that several might also find themselves able to visit Chicago.

He had now much pleasure in moving that the Report of the Council with the statement of accounts be received and adopted.

Mr. Edward F. Daniel, referring to the credit side of the balance sheet in page 15, thought the value of the assets was not quite accurately represented in regard to the item of the back numbers of Proceedings, of which the valuation at cost price was given as £4,520. Although this sum might no doubt represent their actual cost, the latter unfortunately did not always represent the market value. It was only in the last four annual balance sheets that the valuation at cost price seemed to have been introduced; previously the value at the end of 1888 appeared, as far as he could make out, to have been taken at less than £1,500. Taking the amounts realised for extra copies sold during the last four years, he found that it would take fifty-six or fifty-seven years at the same rate to get back the £4,520. It was a great pity he thought to value property of this kind at more than the market value; and it would be better to put it at a much lower figure. If the £4,000 was knocked off, leaving only the £520, the latter he considered would better represent the value of the back numbers.

The President said the question was a fair one to raise; but it seemed difficult to say what was the market value of the back numbers of Proceedings in the ordinary sense of the expression, inasmuch as the stock was held mainly for the purpose of enabling the Members at any time to purchase such back numbers as they might wish. As long as it was intended to carry on the Institution, there was no occasion to contemplate that the market value, whatever it might be, would ever have to be ascertained or realised. The sale price was not below the actual cost price, if interest on the money expended was left out of account; and although it was true that it might take many years to sell off the present stock, yet if it were all to be sold off now it would have at once to be reprinted for the supply of the Members' requirements. The annual accounts showed that former Proceedings were continually having to be reprinted as they became sold out; during last year £61 had been expended in this way, while £93 had been received for Proceedings sold. Unless the stock of Proceedings in hand were included in the assets at nearly cost price, it would appear from the accounts as though the expenditure on printing and engraving the year's Proceedings covered only the copies issued at the time of publication, instead of including, as it did, the stock in reserve for future use. The only practical alternative therefore to the valuation at cost price would seem to be the entire omission of the back numbers of the Proceedings from the assets of the Institution.

Professor Alexander B. W. Kennedy, Vice-President, wished to call particular attention to the paragraph in page 8 of the report, wherein the Members were reminded of a fact which probably many did not know, that the Council would be glad to receive unpublished records of mechanical experiments, or such other communications on engineering subjects as might contain valuable information for the profession, even though not taking the form of papers for reading and discussion at the meetings of the Institution; in order that any of these which they might consider suitable to be so made known might be published in the Proceedings for the benefit of the Institution. That course had already been taken by the Council occasionally; and they desired now to remind the Members of the opportunity which thus existed. It was a matter of considerable importance, and ought to be as widely known as possible. If Members would respond to the appeal, he believed it would be much to the advantage of the Proceedings.

Mr. J. Macfarlane Gray noticed that the item of "subscriptions in arrear" appeared in the accounts both among the receipts in page 13 and also among the assets in page 15; and in the latter case the amount seemed to be given as an estimate, being qualified by the expression "probable value." As the actual sum was so nearly the same in the two entries, he should be glad to hear the explanation of the distinction between the two items, or of their connection with each other.

The President pointed out that the entry of £256 among the receipts in page 13 was the amount actually received during last year under the head of subscriptions in arrear, of which the details were there set forth. Any arrears not paid up by the end of the year, together with any subscriptions then still remaining unpaid for the current year 1892, had to be carried forwards into 1893 as arrears; and the proportion estimated as likely to be realised of the total amount thus carried forwards was entered as an asset of £260 in page 15. This estimate of the probable value was based upon the proportion realised during last year of the total arrears which had similarly been carried forwards at the beginning of 1892 from the previous year.

The motion for the adoption of the Report of the Council with the statement of accounts was then put to the Meeting, and agreed to.

The President said that, in pursuance of the notice given on behalf of the Council at the last General Meeting, he had now much pleasure in proposing the adoption of Special Resolutions for the amendment of the Articles of Association and the By-laws of the Institution, in conformity with the proof already circulated to all the members. It would be seen that the amendments, many of which were mainly verbal, were almost all included under two headings:—firstly, those which dealt with the addition of the proposed new class of Associate Members; and secondly, those attending the omission of all former provisions which, as explained in the Annual Report of the Council, had now become obsolete. Thanks to the previous circulation of the proof, the attention of the Council had been drawn to three further emendations of the Articles, of which he gave the particulars; and the whole of the amended Articles and By-laws had been approved by the Honorary Solicitor, who had also obtained Counsel's opinion upon them. He accordingly moved the Special Resolution printed at the head of the amended Articles in the proof which had been circulated to all the members, namely:—"That the following Articles of Association be the Articles of Association of the Institution, in place of those adopted in August 1878."

Professor Kennedy had much pleasure in seconding the resolution. The object of the amendments was to raise the qualifications for becoming a Member of the Institution: an object which he thought all who belonged to the Institution, of whatever class, would be glad to see carried out.

The Special Resolution was unanimously agreed to.

The President next proposed the Resolution prefixed to the amended By-laws in the proof which had been circulated, namely :—"That the following By-laws be adopted, at and from the registration of the foregoing Special Resolution, as the By-laws of the Institution."

Mr. Joseph Tomlinson, Past-President, had much pleasure in seconding the resolution, which was unanimously agreed to.

The President gave notice that, as a matter of form, a Special General Meeting of the Institution would be held at the offices of the Institution in Victoria Street, Westminster, on Friday afternoon, 17th February, at Half-past Five o'clock, for confirming the two Resolutions which had now been passed.

The President announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected :—

PRESIDENT.

Dr. William Anderson, F.R.S.,	Woolwich.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., F.R.S.,	London.
Sir James Ramsden,	Barrow-in-Furness.

MEMBERS OF COUNCIL.

Dr. John Hopkinson, F.R.S.,	London.
Samuel W. Johnson,	Derby.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Edward P. Martin,	Dowlais.

In consequence of the resignation by Mr. Thomas W. Worsdell of his position as a Member of Council, the vacancy thereby occurring had been supplied by the Council by the appointment of Mr. James Platt as a Member of Council for the present year, his name standing next highest in the voting for the election at this Meeting.

The Council for the present year will therefore be as follows:—

PRESIDENT.

Dr. William Anderson, F.R.S.,	Woolwich.

PAST-PRESIDENTS.

The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Thomas Hawksley, F.R.S.,	London.
Jeremiah Head,	Middlesbrough.
John Ramsbottom,	Alderley Edge.
John Robinson,	Leek.
Joseph Tomlinson,	London.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir James N. Douglass, F.R.S.,	London.
Sir Douglas Galton, K.C.B., D.C.L., F.R.S.,	London.
Alexander B. W. Kennedy, F.R.S.,	London.
Edward B. Marten,	Stourbridge.
Sir James Ramsden,	Barrow-in-Furness.
E. Windsor Richards,	Low Moor.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
William Dean,	Swindon.
John Hopkinson, Jun., D.Sc., F.R.S.,	London.
Samuel W. Johnson,	Derby.
Arthur Keen,	Birmingham.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Francis C. Marshall,	Newcastle-on-Tyne.
Henry D. Marshall,	Gainsborough.

Edward P. Martin,	Dowlais.
William H. Maw,	London.
James Platt,	Gloucester.
T. Hurry Riches,	Cardiff.
William H. White, C.B., F.R.S.,	London.
J. Hartley Wicksteed,	Leeds.

The President reminded the Members that at the present meeting the appointment had to be made of an Auditor for the current year.

On the motion of Sir John Smith, seconded by Mr. Edward F. Daniel, it was unanimously resolved that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year, at a remuneration of Ten Guineas, being the same as heretofore.

The following Paper was then read and discussed:—

"Description of the Experimental Apparatus and Shaping Machine for Ship Models at the Admiralty Experiment Works, Haslar;" by Mr. R. Edmund Froude, of Haslar.

At Ten minutes past Nine o'clock the Meeting was adjourned till the following evening. The attendance was 103 Members and 35 Visitors.

The Adjourned Meeting of the Institution was held at the Institution of Civil Engineers, London, on Friday, 3rd February 1893, at Half-past Seven o'clock p.m.; Dr. William Anderson, F.R.S., President, in the chair.

The following Paper was read and discussed :—

"Description of the Pumping Engines and Water-Softening Machinery at the Southampton Water Works;" by Mr. WILLIAM MATTHEWS, Waterworks Engineer, Southampton.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at Twenty minutes past Nine o'clock. The attendance was 49 Members and 31 Visitors.

A SPECIAL GENERAL MEETING of the Institution was held at the office of the Institution, 19 Victoria Street, Westminster, on Friday, 17th February 1893, at Half-past Five o'clock p.m.; Dr. WILLIAM ANDERSON, F.R.S., President, in the chair.

The requisite quorum of thirty Members being present, the following Special Resolutions for the amendment of the Articles of Association and the By-laws of the Institution, which had been passed at the Annual General Meeting on 2nd inst., were put to the Meeting, and were confirmed :—

"That the amended Articles of Association be the Articles of Association of the Institution, in place of those adopted in August 1878."

"That the amended By-laws be adopted, at and from the registration of the foregoing Special Resolution, as the By-laws of the Institution."

The Meeting then terminated.

DESCRIPTION OF THE EXPERIMENTAL APPARATUS AND SHAPING MACHINE FOR SHIP MODELS AT THE ADMIRALTY EXPERIMENT WORKS, HASLAR.

BY MR. R. EDMUND FROUDE, OF HASLAR.

The principal feature of the present Admiralty Experiment Establishment at Haslar, as of the former one at Torquay, consists in a long covered water-way, in which Models of Ships are towed to ascertain their resistances. The towing is done from a dynamometer carriage driven at definite speeds by a stationary engine working a wire-rope. The models are made of hard paraffine, generally about 14 feet long and something upwards of 1 inch in thickness as finished. They are cast in a mould with an allowance of about $\frac{1}{4}$ inch for finishing accurately to shape, which is done by means of guidance grooves cut in the paraffine by a shaping machine specially devised for the purpose. A brief general description of the Experimental Tank and Apparatus at Torquay was given in a paper read to this Institution by Mr. Robert Gordon in May 1884, page 190; and a full description of the Model Shaping Machine, as it then existed at Torquay, was given in an earlier paper read by the late Mr. William Froude at the Cornwall Meeting in July 1873, page 202. The object of the present paper is to describe the principal novelties of mechanical interest in the experimental apparatus now used at Haslar.

Water-Way and Experiment Carriage.—The water-way at Haslar, Figs. 1 to 4, Plate 1, is nearly 400 feet long, and of nearly uniform section throughout; instead of having only about 200 feet of uniform section as at Torquay. The sides are of concrete and vertical, instead of asphalted earth slopes; and the railway on which the dynamometer carriage runs is bedded on the tops of the side walls of the water-way, instead of being suspended over the water from the roof. The railway is extended beyond one end of the main water-way, so that the experiment carriage can be brought over a dry pit for getting at the experimental apparatus from beneath.

The experiment carriage, which has to span the whole width of the tank, and therefore to run on a railway of nearly 21 feet gauge, is a trussed structure, shown in perspective in Fig. 5, Plate 2. Its principal peculiarity consists in the fact that the members of the several trusses composing it are wooden trunks or boxes about 4 inches square in cross section, made of $\frac{3}{8}$ inch deal and put together with screws and shellac varnish. At the joints formed by the intersections of the various members of the trusses, the sides of the boxes are made to overlap one another over a large area, providing a large surface for screwing and for the adhesion of the shellac varnish. The dimensions of the boxes forming the several members of the girders are assigned so as to bring the sides of the boxes into the right planes to suit these overlaps. In Figs. 6 to 8, Plate 3, are given views to a larger scale of one of these intersections A, Fig. 5, showing the method of overlapping. The whole structure thus produced is remarkably rigid and light. The general design of the carriage is arranged so as to leave clear a sort of central alley provided with a railway, the rails of which are close to the sides of the alley. The object of this secondary railway is to carry the smaller carriages, on which are mounted the actual experimental apparatus of different kinds: so that these may be adjusted on this railway to any desired position fore and aft on the main carriage or truck.

Stationary Engine and Hauling Gear.—The wire-rope, by which the experiment carriage is driven from the stationary engine, is not wound upon a barrel, as it was at Torquay, but is simply led over a grooved sheave driven by the engine, the necessary tension of the wire-rope providing quite sufficient adhesion for the purpose. The engine is a 10-inch Tower spherical engine (Proceedings 1885, page 96), the ample power of which is required only for starting the truck quickly for high-speed experiments. The ordinary speeds of experiment range between 100 and 500 feet per minute; for some classes of models experiments are occasionally made up to about 850 feet per minute, or 9½ miles an hour. The truck has been run at over 1,200 feet per minute, or about 14 miles an hour.

Governor.—The engine is regulated by a governor, acting on the same principle as that used at Torquay and described in Mr. Robert Gordon's paper (1884, page 192), but somewhat improved in detail, having been originally designed in accordance with that principle, instead of being merely adapted to it as was the instrument at Torquay. The arrangement of the governor is shown in Figs. 9 to 14, Plates 4 and 5. The lower ends of the two symmetrical bell-cranks AA are attached to each other by the links BB, having slotted holes which allow the bell-cranks a very small range of freedom of angular motion. When a certain speed of rotation is reached, the centrifugal force of the weights CC overcomes the tension of the spiral spring D, which tension may be adjusted by the coupled screws E and F to any desired amount within a considerable range. But before the bell-cranks, in yielding to the surplus centrifugal force of the weights, reach the outer limits of their very small tether, by means of the hooked rod R they put pressure on the stationary wheel G, pressing it down upon the rotating wheel H above the top bearing of the governor; and by so increasing the friction between the faces of the wheels they cause the stationary wheel to attempt to turn with the governor, and thereby to extend the spiral spring connected with the throttle-valve, and partly to close the latter. The extension of the spring, and the consequent distance of departure of the throttle-valve from its full open position, are proportional to the frictional turning moment applied to the stationary wheel, which moment is in itself proportional to the pressure brought to bear upon it by the bell-cranks; in other words it is proportional to the excess of the speed above that at which the centrifugal force of the weights just equals the tension of the spiral spring. To give greater sensitiveness of action, the bell-cranks are hung not on pin joints but on flat springs S, Figs. 10 and 12, after the fashion of a clock pendulum. The apparent pin-joints at K are only safe-guards, to prevent the instrument from flying to pieces if any of the flat springs should break. While the springs remain sound, the pins do not touch the insides of the holes. It was found advantageous to coat the rubbing face of the stationary wheel G with wood veneer, to give steadier friction.

General Arrangement of Model-Shaping Machine.—The present model-shaping machine is shown in Figs. 15 to 17, Plates 6 to 8. As in the case of the Torquay machine described in the Proceedings of the Penzance meeting, the machine-shaping of the model consists in cutting a series of grooves in the rough model, to the depth of the intended finished surface, Fig. 15, at the successive levels of the series of water-lines in the half-breadth plan, the surface between the grooves being finished off by hand and eye. These grooves are cut by a pair of revolving cutters, between which the model passes, travelling in a fore-and-aft line, while the cutters are moved laterally, receding from and approaching each other symmetrically, in such accordance with the longitudinal travel of the model as to trace in plan upon it the intended horizontal section or water-line, Fig. 17. This due accordance of the lateral motion of the cutters with the longitudinal motion of the model is accomplished by the operator so regulating the cutter motion as to maintain a tracer in contact with the corresponding water-line on the drawing. By suitable mechanism the drawing itself is made to imitate the longitudinal travel of the model, while the tracer imitates the lateral travel of the cutters. In the Torquay machine, at the time of the Penzance meeting, the tracer was maintained in contact with an adjustable template set to the curve of each water-line. Afterwards the tracer was made to follow the line on the drawing itself by eye, assisted by a magnifying glass on account of the smallness of scale of the drawings used in that machine.

The principal features of difference between the shaping machine at Haslar and that at Torquay are as follows.

Firstly, the adjustment of relative level of model and cutters, requisite for cutting the successive water-lines, is effected at Haslar by raising and lowering the cutters themselves instead of the model.

The main advantage of this arrangement lies in a firmer vertical support for the model throughout its entire length, since it now rests directly upon the axles of the model-table V, which are spaced 3 feet 6 inches apart; the arrangement also lessens the vertical height required for the whole machine. The two cutter-spindles R, which run at 2,700 revolutions per minute, are mounted inside stout steel tubes, as shown in Fig. 18, Plate 9; the cylindrical outer surfaces of the tubes are interrupted by a small vertical feather-way to keep the tube from turning round; and also by a small single-thread screw-groove, in which engages a tooth fitted in the nut-wheel A. The raising or lowering of the cutters is effected by rotation of this nut-wheel, communicated to it by the gearing BC driven by the cross-shaft D, on which slides the spur-wheel B fitted with a sliding feather. The rotation of the cross-shaft D is effected by the hand-wheel Q through mitre gear; and the screwed shaft E of the hand-wheel Q simultaneously moves the indicating nut F, Fig. 17, through a distance equal to the vertical rise or fall of the cutters; and this enables them to be set at the levels of the successive water-lines, marked off on the scale G.

Secondly, the lateral motion of the cutters is controlled and made symmetrical by means of the right-and-left-handed screw H, working in the nuts S fitted in the cutter frames, instead of by an arrangement of bell-cranks as was done at Torquay. This screw is worked by mitre gear from the hand-wheel U; and its use supersedes the necessity of the oil cylinder or cataract referred to in page 207 of the Proceedings of the Penzance meeting. As at Torquay, the tension of the cord belt by which the cutters are driven tends to keep the cutter frames apart, and so eliminates any "lost time" due to "slap" of the nut or other parts. As an additional safe-guard, the cutters when cutting are always made to work from midship of model towards the ends, so that they are always being moved inwards, and the friction of sliding of the cutter frames is in the same direction as the pull of the belts. This sliding friction, as at Torquay, is minimised by the counter-balance levers and weights W, which lighten up the weight of the cutter frames.

Thirdly, the drawing table T, Fig. 17, Plate 8, besides being much longer than at Torquay, lies in a horizontal plane instead of standing in a vertical plane. The motion of the tracer is consequently horizontal and lateral, instead of vertical; in other words it is in the same direction as that of the cutter frames; also the copying levers lie in a horizontal plane instead of standing in a vertical plane. The purpose of the much larger relative size of the drawing table in the machine at Haslar, especially as regards its length, is to enable half-breadth plans of the usual scale of a quarter of an inch to a foot to be used for models of large ships. The use of so large a drawing table requires special provisions for accuracy, which constitute a distinct feature in the Haslar machine.

Copying Apparatus of Model-Shaping Machine.—The drawing being made to travel longitudinally in proportion to the longitudinal travel of the model, and the tracer to follow simultaneously the water-line on the drawing, the condition required for the accurate reproduction of the lines of the drawing by the cutters to scale on the model is that at every instant the distance apart of the cutters shall be proportional to the distance of the tracer from the centre line of the drawing. The drawing-table travel, and the length of drawing, may be as much as 12 feet. Now in a very long drawing it is not easy to draw the centre line absolutely straight; nor to fix a long narrow drawing quite straight on a board. Moreover to ensure that the travel of so long a table through so long a distance should be rigidly true and straight would require an expensive structure and great nicety of workmanship. It would probably also involve a degree of frictional resistance to the drawing-table travel, which would be incompatible with so convenient and inexpensive a method of communicating the proportionate longitudinal motion from the model-table to the drawing-table as has been used at Haslar, and previously at Torquay:—namely by light change-wheels, of which the shafts take their motion off the model-table and the drawing-table respectively by stretched pianoforte-wire winding on and off a drum on each shaft, Figs. 15 and 16, Plates 6 and 7.

In order therefore to ensure that the distance apart of the cutters shall be proportional, not to the distance of the tracer from a fixed point in space but to its distance from the centre line on the drawing —the position of this centre line in space being slightly indefinite, owing to the causes already suggested—the fulcrum M of the copying lever J, shown diagrammatically by a single line in Fig. 17, Plate 8, is mounted not on any fixed bracket, but on the frame K, which is itself in fact a lever, pivoted at one end at L, just beneath the line of motion of the cutter end of the copying lever, and held at its other end at the point I, in the line of motion of the tracer, by the frame N. The position of this frame N in the direction of the tracer's travel is regulated by the roller Y, which is held in contact with the back edge of the wide parallel batten P by means of a light weight over a pulley; the front edge of the batten P is adjusted carefully to a uniform distance from the centre line of the drawing. In virtue of this arrangement, lateral deviation of the centre line of the drawing does not affect the distance of the tracer from the centre line.

In order to obtain accurate working in this copying apparatus without running into expensive mechanism—seeing that the actual work to be done by it is almost the smallest conceivable, in fact simply that of sliding over a drawing a tracer consisting of a piece of tracing-paper: so that the only material resistance to be overcome is the friction of the mechanism itself—care was taken in the design to use such mechanical features as give precision against small forces, but involve little friction; for friction tends to cause deflections, or requires heavier and therefore again more frictional working parts to resist such deflections. All redundance of control was also avoided, as tending to cause indecision of working.

As in the Torquay machine, the fulcrum M of the copying lever J can be adjusted so as to give any desired proportion of travel of tracer to that of cutters; the lever J itself has to slide through the fulcrum in working. Also the proportion of longitudinal travel of drawing table to that of model is regulated by change-wheels X; and the "lost time" due to play of teeth in these wheels is eliminated by a weight leading over a pulley, keeping a tension on the table always in one direction.

Method of Feed of Model in Shaping Machine.—The model-table has a maximum longitudinal travel of 20 feet. Its travel is effected, not by a hand winch as at Torquay, but by a simple quasi-hydraulic arrangement, as indicated in Fig. 20, Plate 10, the liquid used being paraffine oil instead of water, in order not to rust the steel wire. The valve is contrived so that the speed of table can be regulated from a certain maximum in one direction to a similar maximum in the opposite direction through every intermediate degree. By opening the cock C—which indeed opens itself, and is only held shut by the foot of the operator while a cut is being made—free communication is established between the two ends of the brass tube T, whereby the self-acting hydraulic travel is instantly stopped, while at the same time the table becomes free to be easily and rapidly moved by hand in either direction. The principal novelty of the arrangement lies in the circumstance that the hydraulic pressure required, amounting to only 14 lbs. per square inch, is maintained not by an accumulator or high-level cistern, but by a little high-speed centrifugal pump at Z, Plate 7, driven by the cord belt which drives the cutters. This arrangement is very convenient, and is found quite satisfactory in working.

Melting and Casting.—The arrangements for melting and casting the models scarcely differ from those described in the paper read at the Penzance meeting, page 204. It may be noticed that it has since been found better to coat the cores with a simple wash of clay, without using any plaster of Paris. It has been found that it is best to cast the models at a temperature not higher than say 160° Fahr.; also that by mixing a little wax with the paraffine, and by remelting it several times in buckets when newly bought, the porousness of the castings, referred to in pages 211 and 214 of the Proceedings of the Penzance meeting, has been almost entirely done away with.

Weighing Machine.—This is used for obtaining the dead weight of the models, in order to determine the amount of ballast required. What was actually required was merely an instrument to weigh up to 1,000 lbs. or so, with greater accuracy than is obtainable with an ordinary spring weighing scale. But a special machine had anyhow to be made; and it seemed that to make a really accurate one would not add much to the cost, while such a machine might prove useful for some purposes. The instrument, which is shown in Figs. 21 to 25, Plate 11, was made at the Admiralty Experiment Works: except the knife-edges and plates, which were supplied by Oertling. It is similar in principle to an ordinary chemical balance, except that it is a steel-yard having one arm 6 inches and the other 5 feet in length, instead of the usual symmetrical beam.

When the model or other weight which is to be weighed is being hung upon the machine, the eye or shackle A to which it is hung is resting in its fixed trunnions; as also are the sling B, by which this shackle is brought to bear on the knife-edge, and the scale-beam C itself. The trunnions of the sling B consist of notches resting on points. All these parts are thereby held in their correct places, so that the knife-edges shall come to bear properly in the centres of the plates when brought into work. Turning the handwheel D raises the centre fulcrum-plate E, which first picks up the scale-beam and raises it off its trunnions J. As the lifting continues, the outer knife-edge picks up the sling B, which in its turn presently picks up the shackle A with the model hanging to it. For the long end of the scale-beam, accuracy of leverage being of less importance, a **V** or notch-plate F, Fig. 25, hangs on the knife-edge G, instead of a flat plate; and at this end the weights are hung on or taken off without any formality of first relieving the knife-edges from strain.

The beam and knife-edges &c. are cased in, to protect them from dust and damp; but the model or other weights to be weighed, as well as the weights used in weighing, hang in the open. In order to make proper use of the evident sensitiveness of the instrument, these also would have to be cased in, to avoid the disturbances caused by draughts of air.

Discussion.

The President considered that this was one of those rare papers, in which a description was given of the improvements indicated by experience in regard to highly important machinery. It was not often that engineers had such a chance of hearing what improvements had been made as the result of actual experience.

Mr. Froude exhibited a transverse segment of one of the paraffine models, cut out from near the centre of its length, showing on one side the longitudinal grooves or water lines as they came from the revolving cutters, while on the other side the surplus material between the water lines had been trimmed off with spoke-shaves, the outer surface being finished by eye to the proper curved shape, but without obliterating the water lines.

He explained that the present paper had been prepared for reading at last summer's meeting at Portsmouth, the apparatus described being in the near neighbourhood. In order that the paper might not be too long, no attempt had been made to describe the general purpose and method of the experiments carried out, or even to give any general description of the experimental apparatus as a whole; but only to describe such of the more important features of mechanical interest as were novel, and as had not been described in the two previous communications to the Institution with reference to the Admiralty Experiment Works. Even in attempting so much, he had scarcely endeavoured to do more than to give what might be called an abstract rather than a complete description; at any rate he had made the paper as brief as he could. It seemed desirable to mention this, because he thought that under the circumstances the title of the paper might possibly lead to the expectation of a more complete treatment than he had been able to give of the subject.

Mr. William H. White, C.B., Member of Council, said it would be seen by all present that the paper was one which required to be carefully studied with the drawings, in order to appreciate with some closeness the remarkable ingenuity which had been displayed in the

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device of the various parts of the mechanism in the Experiment Works at Haslar. It was hardly possible he thought for the mere reading of such a paper to be intelligible; and every one interested in the subject would therefore wish to study it closely. In reference to the scope of the paper, about which Mr. Froude had been so modest, the author had consulted himself on the subject before the paper was written. The Experiment Works, of which Mr. Froude was the distinguished head, were under the Admiralty, and formed a most important part of the section of naval construction with which the speaker was connected. In limiting the scope of the paper, and in giving to the Institution of Mechanical Engineers the mechanical details it contained—comparing the arrangements made at Torquay twenty years ago with those which the working of that establishment had suggested as improvements when transferring the works to Haslar—he thought the author had really done the best thing he could for the Institution. This was scarcely the institution in which could best be described the full purpose for which such experiments were undertaken, inasmuch as that purpose necessarily had regard to the designing and propulsion of ships. The existence of such an establishment in this country, and its working first under the direction of the late Mr. William Froude and since then for many years under that of his son Mr. R. Edmund Froude, had been an immense advantage to the nation, and an enormous economy. In endeavouring to increase the speeds of ships, especially of war-ships, it would not have been possible to proceed with anything like the same certainty, nor could the conditions have been selected in the way that had now been rendered possible owing to the work done in the experimental establishment, first at Torquay and afterwards at Haslar. In working on models with a view to obtain results which could be applied to full-size ships, the essential condition was of course the minutest possible accuracy. Considering the small scale of the models, and the manifold multiplication of the results which must be effected in passing to ships, it did not require any intimate knowledge of the processes to see that, unless the most minute and accurate results were obtained with a model, their application to the design of a ship might be the cause of great error; and in everything which the author had described in the paper it would be seen that no pains had been spared to secure the closest approach to accuracy. Familiar as he himself necessarily was with the work of this establishment, he never went through it without having that feeling impressed upon his mind more and more; and it seemed to him that in many of the machines there were suggestions which could not fail to be of great value to mechanical engineers generally. In later times he believed the truth of what he was saying would be not merely recognised, but would be fully acknowledged by the members of this Institution. The governor, for example, seemed almost as though it were possessed of human intelligence in its behaviour, and certainly it was a great deal better regulated than some human beings. To see the working of the copying machine, and the way in which it scorned temptations to go wrong, was like a lesson in morals. But apart from these features and from the details of the mechanism, there were in other portions of the establishment examples of construction which he thought were well worth studying. Especially to those who were so proud of what might be done in steel he thought that an hour spent over the consideration of the design of the travelling truck or experiment carriage would not be lost. Here could be seen a structure built up of thin wood, which spanned a gauge of nearly 21 feet, carried a considerable weight in its centre, and had gone on doing its work from year's end to year's end without ever coming to grief. By this time Mr. Froude he believed was well assured that it would not give way, although at the period of its design he had pointed out as one of its features that, if he had not allowed a sufficient margin of strength, it would be likely to give way without any warning whatever. It was indeed an admirable example of structural arrangement with so light a material, which had not been supposed to lend itself to the girder method of construction; and he thought it was suggestive of what might be done on a much larger scale under special circumstances.

The work which had been begun by the late Mr. Froude, and was now being carried on by his son, he was confident was of national importance. Before the Admiralty had decided to continue this

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experimental method of investigation at Haslar under new conditions —conditions adapted to experiments which would represent great advances in speed in the future—they had carefully satisfied themselves that the work which had been done at Torquay, and which had been entirely originated by the late Mr. Froude, and to a great extent carried on by him single-handed before it was taken up by the Admiralty, was one which, in the interests of the public, ought to be carried on as a part of the designing of the ships for the navy. There was one private firm in the country—that of Messrs. William Denny and Sons at Dumbarton—which had adopted the same method of experiment for their own benefit. At Spezia, a short time ago, he had had the opportunity of visiting the experimental works which the Italian government had put up, following the works at Haslar as a model. In Russia an experimental establishment was at the present time being created on the same lines; and in the United States an endeavour was being made to follow the same method. These facts he thought were sufficient evidence that the system of experiments, of which the details had been given in the present paper, was one that the nation might well be proud of, having been originated in this country.

Mr. JOHN I. THORNYCROFT was greatly delighted with what had been brought before the Institution in this important paper; and he agreed perfectly with what Mr. White had said, especially as to the great economy that had arisen to the country through the use of these experiments with models; this result had been amply proved. When the late Mr. Froude first called attention to this subject at a meeting of the Institution of Naval Architects many years ago (Transactions 1870, page 87), it was thought that no useful results could be obtained from experiments with models; but it had since been amply proved that most valuable results could be obtained, and within a time which was quite impossible when experimenting with real vessels. The laws governing the relative performance of ships and their models at their corresponding speeds had been so well established that, by the accurate experiments which were now made, the performance of a ship could really be anticipated with a safe degree of accuracy. Of the many beautiful devices described in the paper not one should be overlooked. Though the drawing on the sheet of paper was not necessarily straight and accurate, but might be somewhat curved, the author had shown how, by a most ingenious device, the curvature could be eliminated, and a model could be produced having a perfectly straight axis. This was done without any complication, and also without an expensively constructed apparatus: in fact the apparatus had been cheapened and made more efficient, as not requiring a drawing which was absolutely true. The truck, which he had himself seen, certainly appeared a more substantial structure than it actually was; it seemed to be made of large beams of timber, whereas they were really light hollow trunks or tubes. Many engineers realised that wood, after all, when properly used, was lighter and stronger than steel; and he thought it would be difficult to make so light and strong a structure as this truck even in steel.

Mr. J. Macfarlane Gray thought it would be interesting if the author would explain a little more fully one or two of the more intricate details in the paper: for instance, how the straightness of the centre line in the model was secured from a drawing in which the centre line might deviate somewhat from straightness.

Mr. William Schönheyder enquired whether there was not a minute source of error in the copying arrangement, if the water-line on the drawing was followed with a tracing point. From the construction of the apparatus it seemed to him that the centre line of the two cutter-spindles would correctly imitate that line on the enlarged scale of the model; but that the circumference of the cutters, where they touched the model, would not cut the water-lines of exactly the same shape.

Mr. Froude explained that the tracer was not a point, but a circle proportionally smaller than the circle of the cutters; and it was the circumference of this small circle which was made to trace the water-lines on the drawing.

Mr. Schönheyder noticed also that mention was made (page 36) of the elimination of any "lost time" due to slap of the nut or other parts. The preferable expression he thought would be "lost motion," because it was lost motion that was taken up, not lost time; and moreover it would not matter if there was any time lost. By the word "slap," which he had not before met with, he supposed was meant "slack."

Mr. Bryan Donkin, Jun., asked if it was possible to give any idea of the cost of the whole apparatus as put up at Haslar.

The President expected it would not be easy to give the cost, as the apparatus had grown up gradually to its present state.

Professor Alexander B. W. Kennedy, Vice-President, so greatly admired the methods adopted in the apparatus now described, that he hoped the author would be kind enough to give some of the information which had been left out of the paper, so that it might be recorded in the Proceedings. A reference to the general procedure at Haslar, and to the way in which the governor was connected up, and a general outline of the mechanical part, at any rate, of the method of carrying out the experiments, would be of great interest even to those members who had heard most about it.

Mr. Edward B. Marten, Vice-President, noticed that in the original Torquay model-shaping machine the tracer had had something absolutely to guide it, having been maintained in contact with a template set to the curve of the water-line (page 35); whereas afterwards the tracer had been made to follow the line on the drawing by eye, assisted by a magnifying glass on account of the small scale of the drawings then used. With the larger scale of the drawings now used at Haslar he gathered that the guidance of the tracer was still governed entirely by the eye; and just as in the use of a pentagraph it was always a great deal more difficult to control the accuracy of the work in enlarging than in reducing, it seemed to him that the same difficulty would be likely to occur in the present instance. He enquired therefore whether the drawing used was generally many sizes smaller than the model to be shaped from it.

Mr. FROUDE replied that the drawing was seldom much less than half the full size of the model; and the guiding of the tracer was done entirely by eye, without the assistance now of a magnifying glass.

Mr. MARTEN enquired also how nearly the performance of the completed ship was found to approach to that of the model. Was it always possible to deduce from the model what the ship would do? From what had already been said by Mr. White (page 42), he inferred that this was often the case; and he should be glad to know whether the result of the performance of the models could always be relied on.

Mr. JEREMIAH HEAD, Past-President, was one of those who had enjoyed the advantage of visiting the experimental works at Torquay twenty years ago on the invitation and under the guidance of Mr. Froude's father (Proceedings 1873, page 248), and of seeing in operation the beautiful appliances which had been put up there by him. The present arrangements at Haslar, as now described, appeared to him to be much of the same kind, only on a larger scale and more perfectly carried out. On the occasion of the Torquay visit he remembered that everything worked beautifully; one of the models was having the water-lines cut in it, and another after having already been so cut was being shaped to a smooth form with a joiner's spoke-shave; other finished models were being towed along the whole length of the waterway, and their performance registered by the recording apparatus. It was generally believed that the power required to tow or to propel any vessel through water was directly as the cube of the speed, and also directly as the wetted area; and he should be glad to know how far these primary relations and other formulæ of much interest to engineers and shipbuilders had been found to be confirmed by the results of the experiments carried out on actual models by means of this beautiful apparatus. After the interval of twenty years since the visit of the members to the Torquay establishment, he hoped at no great distance of time they might be allowed an opportunity of seeing the apparatus actually at work at Haslar, and witnessing the experiments as they were now carried out there. Such an opportunity he was sure would be highly appreciated by all.

In looking at the copying apparatus of the model-shaping machine, it had struck him that it was one of the developments of James Watt's copying machine, which on another occasion several of the members had visited in his old workroom at his residence, Heathfield House, Handsworth, near Birmingham (Proceedings 1883, page 599). There they had seen the same machine in principle as the one now described, exactly as James Watt had left it, and as he had last been using it for copying medallions (1883, Plates 82 and 84). There was the same kind of frame, designed carefully for rigidity, so that it could move up and down and carry with it a revolving cutter without any shake at all; the work moved backwards and forwards under the revolving cutter, and at the same time it was fed forwards by a slight motion at each reversal. The original work turned out by Watt with that machine he believed was also still to be seen. The ship model now exhibited was evidently a development of the same idea.

The experiments at Torquay and Haslar had been spoken of as an enormous benefit to this country (page 42); and subsequently it had been mentioned that other countries were already following suit —America, Italy, and Russia—whose mercantile vessels were even now in competition with our own on the high seas, and whose war vessels might some day possibly become so in a less friendly sense. It seemed to him therefore not quite so certain that these experimental investigations were going to be in future so decided a benefit to this country as distinguished from all other countries. But at any rate he thought there could be no hesitation in saying that the labours which had originated with the late Mr. Froude and were now being continued by his son had resulted in great benefit to the world at large.

Mr. JAMES ARMER noticed that the old waterway at Torquay had been made with sloping sides (page 32), while the new one at Haslar had vertical sides. It was well known that the shape of the transverse section of the channel had a considerable effect on the power required to propel a vessel. It would therefore be interesting to learn why the section had been altered in shape, and whether practical results might be more correctly deduced from the experiments in the present waterway having vertical sides.

Mr. FROUDE replied that the sectional area of the new waterway at Haslar was not quite so great, but was nearly as great, as that of the old one at Torquay. Experience of the waterway in the Torquay tank had assured him that the slightly smaller sectional area at Haslar was quite enough. Vertical sides had been adopted for the waterway at Haslar, not at all because of any supposed effect of shape of section of waterway on model resistance, but mainly for the convenience of being able to use the side walls to carry the railway on which the truck was to run, instead of suspending it from the roof, as had had to be done at Torquay owing to the greater width of the top of the waterway with its sloping sides.

The words "lost time" and "slap" (page 46) were terms which he had learnt from his father, although possibly they might not be in such common use at the present time. "Lost time" he understood to mean the same as lost motion; and "slap" to mean the same as looseness of any kind in a joint or in gearing.

In reference to the copying gear of the model-shaping machine, and Mr. Macfarlane Gray's question (page 45), it should be understood that the wide parallel batten P, Fig. 17, Plate 8, which was adjusted parallel to the centre line of the drawing, itself formed the clip by which the drawing was fixed on the table; and it was easy, in clamping it down, to spring slightly either the batten or the drawing or both, so as to bring them into mutual accordance in respect of any such unavoidable deviations from perfect straightness as either might possess. The manner of eliminating the errors which would otherwise arise from the deviations of the centre line of the drawing might perhaps be most readily understood by observing

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that the copying lever J and the frame K together formed, so to speak, a pair of scissors. Just as the distance between the points of a pair of scissors depended on the distance between the two bows—regardless of any deviation of the pair of scissors as a whole,—so the distance of one end of the copying lever from the point L, which was equal to the half distance between the cutters, depended on the distance of the other end from the point I, which was equal to the distance of the tracer from the centre line of the drawing—regardless of the deviations to which this point I was subject in tallying with the deviations of the centre line.

The question asked by Mr. Marten (page 47), as to how far the performances of actual ships bore out the results of the experiments with their models, was one which could not be quite definitely answered, owing to the uncertainty attaching to the results of steam trials—an uncertainty evidenced by the contradictory results obtained with sister ships, or even with the same ship on different occasions. All he could say was that, although on *à priori* grounds it was not unlikely that in full-sized ships the comparative resistances of hulls of widely different type or size might tangibly differ from that estimated from the model experiments, he had never yet ascertained that any such differences existed.

In answer to Mr. Head's question (page 47), he might say that the broad principle of resistance being proportional to wetted surface was correct in a rough way, but with important limitations. In other respects he thought it could not be said that the earlier and more abstract formulæ for resistance were borne out by experiment.

Having said this much, he feared that he could not profitably go further in response to the kind invitations of Professor Kennedy and other speakers. To extend the scope of the paper to questions concerning the resistance of ships, or in fact to questions of the object and purpose of the experiments, would involve travelling over far too wide a field. The mechanical features of the apparatus described in the paper he feared he should not succeed in rendering any clearer verbally. When read at leisure in connection with the drawings, he thought the description given in the paper would be found sufficiently clear by every one who had reason for studying any particular portion of the apparatus. His principal object had been to describe the modifications which had been made in the experimental apparatus now used at Haslar, in order that the present paper, taken in connection with the two which had preceded it in 1873 and 1884, might form so far a complete and compendious record of the more prominent and novel mechanical contrivances used at the Experiment Works from first to last.

In reference to the initiation of the Admiralty Experiment Works, he thought it ought to be said that, next to his father, this was owing to Sir Edward Reed, who had been the Chief Constructor at the time when his father had been making the original experiments at his own cost. Sir Edward Reed had been greatly struck with the results obtained from those early extemporised experiments with ship models; and had suggested to his father, who would not have been bold enough to think of such a thing himself, that he should draw up a proposal and estimate for an experimental establishment. That proposal had been carried through, and had been the origin of the Torquay establishment.

The PRESIDENT was sure that the members would accord to Mr. Froude a cordial vote of thanks for the paper he had read, and for the materials he had furnished for illustrating so fully the highly ingenious mechanism he had described. No one he thought could help being much struck by the singular fact, which would seem to be established by Mr. White's remarks (page 44), that in a maritime nation like England, having he believed a much larger tonnage of mercantile and war shipping than the whole of the rest of the world put together, there was not a single public testing establishment of any kind beyond the Admiralty Experiment Works; and these he believed were not open to private shipbuilders to use.

Mr. WHITE added that, although there was no public establishment, and only the one private establishment of Messrs. Denny at Dumbarton, which he had mentioned, there were also proposals to establish similar experimental works in connection with classes in naval architecture at the University of Glasgow, and at the College of Science, Newcastle-on-Tyne.

The PRESIDENT said he had for a long time been advocating that in some of the science schools, instead of the usual equipment of testing machines for testing materials, and the experimental steam-engines, there should be apparatus whereby experiments in hydraulics could be carried out, not only for ascertaining the resistance of floating bodies, but likewise for enabling the students to make practical experiments on the gauging of water flowing over weirs, the resistance of water in pipes, and so on. At present there was not one of the science colleges, he believed, in which anything of that kind could be done on a large scale. With the exception of Messrs. Denny's works at Dumbarton, none of the large shipbuilding centres had anything of the kind, which seemed to him to be all the more surprising because there could not be the least doubt, from what Mr. Froude had said, and what was indeed common knowledge, that the benefits conferred by the apparatus described in the paper and by the experiments that had been made with its aid were valuable beyond all calculation: so much so indeed that, as Mr. White had mentioned (page 44), foreign nations at last realised this fact, and were now following in our wake.

DESCRIPTION OF THE PUMPING ENGINES AND WATER-SOFTENING MACHINERY AT THE SOUTHAMPTON WATER WORKS.

By Mr. WILLIAM MATTHEWS, Waterworks Engineer.

In 1851 the Southampton Corporation equipped a pumping station at Mansbridge, and obtained a supply of water from the River Itchen, Fig. 1, Plate 12. In 1865 additional plant was added; and this source was used until 1888, when new works were inaugurated at Otterbourne, eight miles from Southampton, drawing a supply from wells and headings sunk in the chalk.

Mansbridge Pumping Engines.—The old plant at Mansbridge consists of—firstly, a pair of single-acting Cornish beam engines, made and erected in 1851 by Messrs. R. and W. Hawthorn, of Newcastle-on-Tyne. The cylinders are 38½ inches diameter with a stroke of 8 feet; jet condensers are used, and the working pressure is 15 lbs. per square inch. The engines make 10 strokes per minute, and in ordinary work consume 4·7 lbs. of Welsh coal per I.H.P. per hour. The pumps are of the bucket and plunger kind, 14¼ inches diameter and 8 feet stroke; they have Harvey and West's valves, and can each lift 734,000 gallons per day against a head of 200 feet. Secondly, a pair of rotative beam engines, coupled together with a common fly-wheel, made and erected in 1865 by Messrs. Harvey and Co., of Hayle. The cylinders are 40 inches diameter with a stroke of 8 feet; jet condensers are used, and the working pressure is 20 lbs. per square inch. The engines make 12½ revolutions per minute, and in ordinary work consume 4·9 lbs. of Welsh coal per I.H.P. per hour. The pumps are of the bucket and plunger kind, 18¼ inches diameter and 8 feet stroke; they have Harvey and West's valves, and each can lift 1½ million gallons per day against a head of 200 feet. Indicator diagrams from each kind of engine are shown in Figs. 9 and 10, Plate 19.

Otterbourne Pumping Engines.—At the Otterbourne works there are a pair of compound rotative beam engines, shown in Figs. 2 to 6, Plates 13 to 16, with supporting columns, entablature, and spring beams attached to the engine-house walls. Each engine is independent, with its own crank-shaft and fly-wheel; but both pump into one delivery main. At a speed of 18 revolutions per minute each can pump 2 million gallons in 24 hours. The cylinders are steam-jacketed and placed side by side; the high-pressure are 28½ inches diameter with 4 ft. 9 ins. stroke, and the low-pressure 38¼ inches diameter with 7 feet stroke. The intermediate steam-receivers are unjacketed, and are placed underneath the high-pressure cylinders, forming their bases; they are 2 ft. 9 ins. diameter and 4 ft. 6 ins. high inside. The steam pistons are 9 inches deep, cast solid and fitted each with three plain steel rings. The piston-rods are of steel, 4¼ inches diameter.

Valves.—The high-pressure cylinders have valve-chests at both ends, connected together by a cast-iron pipe with a copper expansion-joint. They are fitted with Meyer's expansion slide-valves, giving a variable cut-off from one-eighth to three-quarters of the stroke, three-tenths being the normal. The valves are of cast-iron, and the spindles of steel. The low-pressure cylinders also have valve-chests at both ends, which are connected by means of two cast-iron side-pipes. Each valve-chest contains separate steam and exhaust valves of cast-iron with steel spindles, the valves being of the ordinary double-seated type. Pneumatic dash-pots are fitted to the valves; but as at present the valves fall almost noiselessly, their use is not resorted to, and the plugs are left full open to the air; the dash-pot pistons however form capital guides for the valve spindles. Each valve gear is actuated by means of a steel lay-shaft F, 4 inches to 3½ inches diameter, which is worked from the crank-shaft of its own engine by means of a pair of bevel wheels B, 2 ft. 2⅜ ins. diameter. The lay-shafts are carried under the floor, close to the cylinders; and by means of cast-iron cams, fitted with steel treads, they raise and let fall the plug rods connected with the low-pressure valves. The plug rods are 2⅜ inches to 1⅞ inch diameter, and terminate at bottom with rollers; and as the cams revolve in an oil bath, the wear on them is reduced to a minimum. Close to the high-pressure cylinders the lay-shafts are each connected by means of a pair of spur wheels S, 1 ft. $7\frac{1}{2}$ ins. diameter, with a $3\frac{1}{2}$ inch countershaft, which has at one end a crank and pin with $2\frac{7}{8}$ inches stroke; this gives a travel of $5\frac{3}{4}$ inches to the main slide-valve spindle, to which it is connected by a short connecting-rod. The expansion slides have each a travel of $6\frac{1}{2}$ inches; they are actuated from above by means of rods and cranks, the actual motion being derived from the end of the radius-rod of the parallel motion. The shaft connecting the ends of the rods is hung in brackets, and at one side projects beyond, and has a crank keyed on it, which thus acquires the rocking motion of the radius-rod. A steam starting-gear is arranged, so that with a single lever steam can be admitted into the low-pressure cylinder either above or below the piston at any position in the stroke.

Condensers, &c.—The surface condensers C, Plates 14 and 16, are of cast-iron and vertical, 3 ft. 3 ins. diameter, fitted with 250 brass tubes 1 inch outside diameter and 5 ft. 9 ins. long between the tube plates, to which they are secured by wooden ferrules. The air pumps A are of the usual vertical kind, 22 inches diameter and 30·8 inches stroke. The buckets are of cast-iron 18 inches deep, without rings or packing. The foot, delivery, and bucket valves are all of india-rubber. Pumps for feeding the boilers and charging the air vessel are worked off the same cross-head, which, hung from the beams by double rods, gives motion to the air pumps. These boiler feeds have been put out of use, owing to trouble with the grease in the boilers. The cylinder jackets receive steam direct from the main boilers, which are at a lower level, so that the jackets drain back into them.

Beams.—The engine beams are of cast-iron, each composed of two panelled and moulded flitches, $2\frac{1}{4}$ inches thick in the panels and $4\frac{1}{4}$ inches at the mouldings. The flitches are 9 inches apart, 5 feet deep in the centre, and rounded at the ends to a radius of 9 inches; they are 23 ft. $0\frac{17}{32}$ inch between extreme centres. Cast-iron balance-weights are fitted on the cylinder end of each beam. The beams swing in heavy plummer-blocks with brasses 9 inches diameter and

11 inches long, the steel gudgeons being 13¼ inches diameter through the beams. The piston-rod cross-heads are hung from one end of the beams by the usual side-links and parallel motion; the air pumps and main water pumps have no parallel motions, but are worked from plain gudgeons fixed in the beams. The fly-wheel connecting-rods are of wrought-iron, hung to a gudgeon between the beam flitches; each has a stroke of 6 feet, and is 20 feet long between centres, 7¾ inches diameter at centre, and 5¾ inches diameter at each end. Both brasses are 7 inches diameter, the upper 8 inches long and the lower 8½ inches, fixed in the strap ends with gibs and cotters.

Shafts and Fly-wheels.—The shafts and cranks are of wrought-iron, and the crank-pins of steel. The shafts are 12½ inches diameter, except in the outer bearings; and the crank-pins are 7 inches diameter and 8½ inches long. The bearings in the inner plummer-blocks are 12½ inches diameter and 16 inches long, and in the outer 9½ inches diameter and 13 inches long. The fly-wheels, 18 feet diameter with six arms, are cast in three pieces, securely dowelled together and further secured by two wrought-iron rings shrunk on the wheel bosses, one on each side. The bosses are bored out 12½ inches diameter, and secured to the crank-shafts with two keys to each wheel.

Pumps.—There are two pumps worked off each engine, Plates 14 to 16, one low-lift L and the other high-lift H; the former lifts water from the well W, and delivers it up to the softening works; the high-lift receives it by gravity after softening, and forces it up to the high-level reservoir on Otterbourne Hill, Plate 12. Ten per cent. of lime water has to be added to the well water in the process of softening; and as this lime water is made from softened water, the high-lift pumps must always deliver 10 per cent. more water than the low-lift. The pumps are hung from the engine beams so that their strokes shall be 7 feet for the high-lift pumps and 5 feet for the low-lift.

The low-lift pumps L, Plates 14 to 16, are of the bucket and plunger type, and are hung one down each well-tube by means of 23-inch pipes P and two 2-inch hanging rods. The working barrels are 22 inches diameter, placed near the bottom of the suctions. The buckets are of cast-iron, 30 inches deep, with four water grooves but no packing or rings. The bucket and suction valves are alike, with double india-rubber valves working against cast-iron guards and grids. The suction valves can be drawn up the 23-inch pipe for examination by means of a large eye-bolt, when fished for with a chain and hook. The plungers are of cast-iron 20 inches diameter; and from them the buckets are hung by means of $2\frac{1}{4}$-inch iron rods D with steel couplings and keys. Each rod is about 65 feet long over all; and when running fast it was found that whipping took place, with a consequent loosening and shearing of the coupling keys. To remedy this, each rod has had two sets of rollers fitted to it; there are three rollers in each set, fixed in a strong iron framework which is attached to the rod; and the 23-inch pipe P itself forms the roller path, care being taken to alter the position of the rollers occasionally, so that grooving shall not take place. This plan has proved quite successful, and no difficulty is now found in keeping the keys tight. The pumps deliver through 18-inch stop-back valves V of the regular hinged-flap kind, into a common annular air-vessel R, 4 feet diameter inside and 13 feet 10 inches high; the annular space is formed round a pipe of $23\frac{1}{2}$ inches diameter, and the delivery main Y is 24 inches diameter.

The high-lift pumps H, Plates 14 to 16, receive their water from a higher level, and their suctions are furnished with open-topped stand-pipes T. The pumps are plunger pumps, but so designed that they are double-acting on the delivery, Fig. 7, Plate 17. The plunger is of cast-iron unpacked, $19\frac{1}{2}$ inches diameter and 3 feet 6 inches long in the working barrel; above and in the stuffing-box it is 14 inches diameter. The suction and delivery valves are four-seated, with easy and ample waterways, although the lift is only $1\frac{1}{4}$ inch; they are of cast-iron with gun-metal seats. The water is forced from under the plunger through a loop pipe and through the delivery valve to the top side of the plunger, whence it is discharged through a 14-inch stop-back valve into an air-vessel J common to both pumps, 3 feet 9 inches diameter and 12 feet 6 inches high with a domed top. From the air-vessel a 24-inch main M leads up to the high-level reservoir on Otterbourne Hill, Plate 12. The delivery valve-boxes are furnished with 3-inch relief-valves.

Each pump has a cross-head and guide attached to the prolongation of the plunger above the stuffing-box, and these work in guide grooves I fitted against the foundation walls. The cross-heads are connected with the beam gudgeons by pairs of braced connecting-rods, 27 feet long between centres; for the low-lift the rods taper from $4\frac{1}{4}$ inches to $2\frac{5}{8}$ inches diameter, while for the high-lift they are $3\frac{3}{4}$ inches diameter at the ends, and $6\frac{1}{2}$ by $4\frac{1}{2}$ inches oval section at the centre. The brasses are alike at both ends, 3 inches diameter and $3\frac{1}{2}$ inches long for the low-lift, and $3\frac{3}{4}$ inches diameter and $5\frac{3}{4}$ inches long for the high-lift; all are furnished with strap ends, gibs, and cotters.

The pumps upon trial were found by actual measurement of water to have a slip of 2·73 per cent.

Boilers.—Steam is supplied by three steel boilers, Plate 16, each 28 feet long and 7 feet diameter, having two flues of 2 feet 9 inches diameter, in which are four Galloway tubes tapering 8 inches to 4 inches diameter. The shell plates are 7-16ths inch thick, the ends 5-8ths inch, and the flue-tubes 3-8ths inch. The average tensile strength of the steel was 27·17 tons per square inch, with an elongation of 24·9 per cent. Each boiler is fitted with a Cowburn's dead-weight safety-valve, and also with Hopkinson's combined low-water and pressure safety-valve. Two boilers easily keep steam at 60 lbs. pressure with both engines working, and the consumption of coal is very moderate.

Cost of Pumping.—The total cost of pumping during the years 1890 and 1891 has been 0·634 penny per thousand gallons.

Trials.—The engines, pumps, boilers, and tools in the repairing shop were all supplied by Messrs. James Simpson and Co., of Pimlico; and the following are the results of the trials which were made shortly after the starting of the engines. Indicator diagrams are shown in Fig. 8, Plate 18.

Trials of Engines.

Engine		A	B
Date of Trial	1888	Nov. 1.	Nov. 9.
Duration of Trial	hours	10½	10½
Barometric pressure	lbs. per sq. in.	14·60	14·64
Boiler-pressure above atmosphere	lbs. per sq. in.	60·6	60·0
Vacuum in condenser below atm.	lbs. per sq. in.	14·00	13·98
Revolutions, total during trial	revs.	10,850	11,060
„ per minute	revs.	17·22	17·55
Horse-power, indicated	I.H.P.	115·55	117·93
„ actually obtained	H.P.	98·00	100·02
„ expended in friction	H.P.	17·55	17·91
Mechanical efficiency of engine	per cent.	84·81	84·80
Coal consumed, total during trial	lbs.	1,757	1,750
„ „ per hour	lbs.	168	167
„ „ per I.H.P. per hour	lbs.	1·454	1·416
„ „ per actual H.P. per hour	lbs.	1·714	1·670
Ashes, total made during trial	lbs.	14	15
Quantity of Water raised, high-lift pump	gals.	955,125	973,612
„ „ „ low-lift „	gals.	868,651	885,464
Head of water against high-lift „	feet	159·73	161·15
„ „ „ low-lift „	feet	58·90	57·70
Duty of engine per cwt. of coal,	millions of foot-lbs.	129·3	132·8

Water-Softening Machinery.—The softening plant, shown in Figs. 11 to 20, Plates 20 to 26, is capable of satisfactorily dealing with from 2¼ to 2½ million gallons per day of 24 hours; and by the addition of seven filters and two lime-water cylinders, for which space is provided, Plate 21, nearly 4 million gallons per day could be treated. The softening process may be divided into three operations:—first, the preparation of cream of lime; second, the preparation of lime water and its admixture with the hard well-water; third, the filtering of the turbid water after softening.

Cream of Lime.—The cream of lime is prepared in the following manner. The raw lime from the kilns is tipped into two mechanical slaking machines K, Plate 21, 4 feet diameter and 3 feet deep, in which it is stirred up by revolving arms, and wetted by the admission of water from the mains. Thus slaked and mixed with water, the cream of lime flows through screens into a large tank C, where it is stored for use, a week's supply being furnished at each slaking. The tank is made of concrete lined with blue bricks; it is 25 feet by $19\frac{1}{4}$ feet with a sloping bottom, 5 feet deep at the sides and 7 feet at the centre. Compressed air can be discharged into it through pipes, so as to agitate the cream of lime occasionally and thereby prevent its consolidation.

Lime Water.—For the preparation of lime water are provided two large open-topped steel cylinders L, Plate 22, 9 feet diameter and 11 feet high, with their lower ends coned. Into these the cream of lime is pumped at intervals, and occupies the coned bottom, Fig. 14; softened water from the mains is admitted to a tank fixed above the cylinders, and flows thence through pipes and valves into the cylinders, being admitted near the bottom of each cylinder. This water has therefore to rise through the cream of lime, of which it carries a portion with it, forming lime water. The latter is drawn off by collecting pipes from the upper part of the cylinders, and flows through regulating valves into the mixer M, where it meets the hard water from the well. The mixer is a large open-topped steel tank, fitted with baffle-plates; the 24-inch main Y from the well pumps enters it at one end, and the lime water nearer the centre; and owing to the action of the baffles a thorough mingling of the two takes place before the lime water passes from the end of the mixer into the distributor D, Plate 21. The latter is a long steel trough, into which the lime water flows from the mixer, and from which it is discharged in a thin sheet over the entire 40 feet length of one side of the trough, as over a weir; and as the lime water falls about 3 feet into the softening tank S, the most complete combination is assured of the hard water and the lime water. The softening tank S is of brick and concrete, 76 feet long, 44 feet wide, and 6 feet deep along one side, sloping to 7 feet along the other. The water travels through it slowly, in order to give time for the chemical action of softening to be actually and surely finished before the water is admitted to the filters F.

Filters.—The filters, shown in Figs. 15 to 20, Plates 23 to 26, are thirteen in number, and their function is to remove the carbonate of lime, which is present in the water as an insoluble precipitate after the softening has been effected. Had this to be removed by subsidence, as was the case in the old process, immense reservoirs would be necessary. The filtering material is cotton cloth mounted on perforated zinc. Water from the softening tank is admitted to the filters through 6-inch inlet-pipes, the mouth of each being fitted with a heavy leather-faced flap-valve, which is opened by a lever from the front end of the filter, Plate 24. Each filter consists of a cast-iron open-topped tank, in which is placed a horizontal hollow shaft carrying twenty discs of 3 feet diameter. Each disc is formed of a light circular cast-iron frame, covered on either side with perforated zinc, over which is stretched the cotton filter-cloth, secured round the circumference of the disc by two wrought-iron clip-rings that are just bound together by copper wire wound round studs, Fig. 16, Plate 23, and Figs. 19 and 20, Plate 26. The water percolates through the cloth, and finds its way along the hollow shaft, and through valves and pipes, to the clear-water tank T, Plates 20 and 21, whence it flows to the high-lift pumps. The deposit of carbonate of lime thus accumulates upon the faces of the discs, until the time arrives when it becomes necessary to clean it off. This is done by means of water spray, applied while the discs are revolving. The disc-shaft is mounted in trunnion bearings, and is made to rotate by means of a spur wheel and pinion inside the front end of the filter, Plate 24, driven by bevel gearing outside. Small water-pipes with spray holes in them are placed between each pair of discs; and upon high-pressure softened water being admitted, the issuing jets wash the deposit off the cloth surfaces, Fig. 16, Plate 23. The spray pipes are $\frac{3}{4}$ inch diameter, and are made to rise and fall, so as to command the entire surface of the revolving discs. The filters are furnished with outlet valves V for the filtered water; and also with waste valves W, whereby the deposit washed off is carried away to waste pits outside, Plate 21.

Cost of Softening.—This softening apparatus acts efficiently and economically. The cost of softening during the two years 1890 and 1891 amounted to only 0·243 penny or one farthing per thousand gallons. The machinery was made and erected by Mr. John Cochrane of Barrhead for the Atkins Filter and Engineering Company, the details having been worked out by their manager, Mr. W. G. Atkins. A complete detailed description of the plant and machinery has been given by the author in the Proceedings of the Institution of Civil Engineers, 1892, vol. cviii, page 285.

Discussion.

Mr. MATTHEWS said this paper had been prepared for reading at the last summer meeting, had time admitted, in connection with the visit paid by the members on that occasion to the Otterbourne works. He would anticipate the exception which might possibly be taken to the steam receivers of the new engines being unjacketed, by explaining that the design of the engines had been somewhat hampered in regard to the amount of money to be spent upon them ; and this was one of the questionable directions in which it had been thought that a saving in first cost might be effected. As to the whipping or transverse vibration of the long pump-rods (page 57), which had been remedied by putting rollers in, it should be added in justice to Messrs. Simpson, who had built these engines, that they were really not answerable for it ; for originally the pumps had been intended to raise water from not such a great depth as was afterwards found in practice to be necessary, owing to the supply at the shallower depth not being so large as had been expected. The engines had thus to lift the water with a much greater head on the low-lift pumps than had been expected ; and it was only when they were pumping with the water low down in the well that the whipping had taken place.

As to the cost of the pumping, which was stated (page 58) to be 0·634*d*. per thousand gallons through 1890 and 1891, the cost for the past year 1892 had just been made out ; and with various economies which had been effected it had been reduced to 0·612*d*., the price of Welsh coal being 18*s*. 9*d*. per ton delivered in the siding at the works. Similarly, with regard to the cost of softening, this had been reduced from 0·243*d.* to 0·202*d.* per thousand gallons; and it was anticipated that during the present year it would be still further reduced. Hitherto the waste deposit from the filters had been allowed to go into open pits at the lower level of the works, whence it had to be dug out and carted up to another part of the land, and deposited in an old chalk pit; but arrangements had been completed since the visit of the members, for pumping the waste as it came from the filters at once up to the highest level at the top of the land, and there letting it subside in a pond to a certain extent, and then shooting it direct into the old quarry. By this plan it was expected that a saving would be effected which would probably bring the cost of softening down to below 0·200*d.* per thousand gallons.

The PRESIDENT asked whether that cost included any charge for the sinking fund.

Mr. MATTHEWS replied that it did not. The sinking fund for the works had been calculated on a life of thirty years, and came almost exactly to another farthing per thousand gallons.

The lime used for softening the water was obtained on the site of the works, and was burnt from the chalk. It was found that this was the most important point to which attention had to be paid in connection with the softening. Unless the lime was very pure, free from any admixture of earthy matter, it had a most serious effect upon the filter cloths, causing them to be eaten away extensively.

Mr. EDWARD B. MARTEN, Vice-President, asked at what depth the chalk water was met with down the well, and how high it had to be lifted; also how much it was lowered in the well by the pumping, and whether it became any less hard by more pumping, or whether it was always of the same degree of hardness. Was it the tendency of the water in such wells to become either better or worse in respect of hardness? The wells themselves he thought were particularly interesting, because they had been sunk entirely by boring; they really were big borings, 6 feet in diameter.

(Mr. Edward B. Marten.)

In regard to the whipping that had been found to take place in the long rods by which the buckets were hung in the pump wells (page 57), he enquired whether anything else had resulted from it besides the loosening of the couplings. Did they strike so violently against the inside of the pipes as to cause injury to them, or only to the couplings or keys of the rods?

It seemed from the drawings that all the softened and filtered water from the clear-water tank flowed to the high-lift pumps through the surface condensers, which he believed was not a usual plan for water works, or at any rate not on such a large scale; and he enquired how it was found to answer. Although probably it did not do any harm to the water, he wished to know whether it affected the taste at all: whether the water had a fishy taste or any peculiar flavour after it had been through. Was there any perceptible difference in the taste of the filtered water as compared with the unfiltered? The latter was no doubt extremely fresh and nice for drinking. Was there any analytical difference between the softened water when it went into the surface condensers, and when it came out? If there was any chemical change, he should like to ask what ingredients altered in passing through the surface condensers. Also what was the hardness of the water as it came from the well, and what after the softening?

For cleaning the deposit off the faces of the filtering discs he asked whether any arrangement had been tried of reversing the current, so as to lift the deposit off the surface of the filtering cloth, and so wash it away.

In estimating the duty of the engines (page 59), was it calculated upon the displacement of the pumps? or was an allowance made for their slip of 2·73 per cent.? So small an amount of slip showed that the pumps delivered very nearly the full quantity due to their displacement; and their duty was good, even if it was calculated on the displacement, while it was still better if it represented work absolutely done.

Mr. EDWARD PERRETT asked how long the filter cloths lasted. Also, when the washing took place from the outside, as shown in

Fig. 16, Plate 23, was not the fine deposit from the hard water washed inwards through the filter cloth, instead of simply being all washed off the outer surface? What means were there of replacing the cloths when worn away? had the whole of the filtering apparatus to be taken out, in order to put fresh cloths on?

Professor Alexander B. W. Kennedy, Vice-President, judging from the particulars given of the trials of the engines (page 59), thought that perhaps full justice had not been done to the engines. Taking the trial of engine A, the indicated horse-power was 115·55, and the horse-power actually obtained was 98·00. The latter he had been working out, and found it corresponded exactly, if his calculation was right, with the quantity of water given at the bottom of the table. Then the difference, or 17·55 horse-power, being expended in friction, the mechanical efficiency of the engine was given as 84·81 per cent. Obviously however the friction included all the friction of the water in the pipes, as well as the engine friction: so that, although it was right to put down the difference of 17·55 horse-power as expended in friction, it was hardly fair to say that the mechanical efficiency of the engine was only 84·81 per cent., because this was really the mechanical efficiency of the engine and of all the pipes to the reservoir, which latter might or might not be a considerable proportion. At any rate 84·81 per cent. was a somewhat low efficiency for the engine by itself, and it might quite well have a fairly high efficiency if the pipe friction were allowed for. He had himself been intending to ask almost the very question which Mr. Marten had already asked (page 64), as to how far the author was sure of the quantity of water raised, or whether this was ascertained only from the number of strokes of the pumps, allowing for a known percentage of slip.

Mr. Sidney Straker asked whether the standard of purity was maintained throughout the whole period of filtration. It appeared to him likely that the cloth would be more porous when the water first began to be filtered through it, and that, as the deposit of carbonate of lime gradually accumulated on its outside surface, the

(Mr. Sidney Straker.)

water after a certain period would percolate through more slowly than it did in the first instance when the cloth was clean and it could go through more rapidly. It seemed therefore that the standard of purity would be rather variable; but it was fair to presume that, the softening apparatus having now been in use for so long a time, it was found practicable to filter the water pure enough. Some years ago, when feed-water was softened by Clark's process, a good deal of trouble had been experienced in extracting the precipitated carbonate of lime from the water; and the present plan having proved really practicable appeared to him to be a solution of a complex question. The original idea he believed, for cleaning the filter cloth of the solid matter deposited upon it from the water, was to inject steam into the effluent pipe or hollow shaft, during the time that the spray of water from the small water-pipes between the discs was playing on the outside of the cloth, so that the steam might blow outwards through the cloth and prevent any of the deposit from getting driven into the inside of the filter. He should like to know whether that plan had ever been tried; and also whether an injection of air instead of steam had been tried, for counteracting the penetrating action which the impinging water would have upon the filter cloth. In a filter at work at the Barry Docks near Cardiff he believed that, in accordance with another scheme of Mr. Atkins, charcoal blocks were used, instead of cotton cloth; and he enquired whether they had been tried at Southampton. It appeared to him to be a matter of great importance to all connected with this class of engineering to be able to extract the softening agent or insoluble carbonate of lime, so as to enable the water so softened to be used for manufacturing purposes; and any plan by which this could really be done on a practical scale was certain to come largely into use.

Mr. Charles Cochrane, Past-President, pointed out that bicarbonate of lime was itself soluble in water, and was what rendered the water hard; and by the addition of lime water, which was a highly diluted mixture of lime and water, the soluble bicarbonate was reduced to the insoluble monocarbonate. The latter being thus precipitated was then deposited upon the filter cloth, whereby the turbid softened water was rendered clear. This he believed to be the correct account of what took place in the softening and filtering process. In the case of water acting upon any of the limestone rocks, which were found in so many parts of this country, the air with its small dose of carbonic acid imparted a certain minute amount of carbonic acid to the rain-water; and it was only from the carbonic acid in the rain-water falling upon the outcrop of the chalk in the great London basin—and elsewhere when the chalk was covered only by porous beds of gravel or sand, instead of by impervious clay—that the insoluble monocarbonate of lime suspended in the water was enabled to take up the additional equivalent of carbonic acid and become converted into bicarbonate of lime, which being soluble was at once dissolved by the water and rendered it so hard. It was to expel this extra dose of carbonic acid, which had rendered the monocarbonate of lime soluble as bicarbonate, that the process of softening was carried out in the manner described in the paper. The object of calcining the chalk, by burning it in the kiln to expel the carbonic acid, was to enable the caustic lime so obtained to be used as a base for uniting itself with the extra dose of carbonic acid in the soluble bicarbonate, whereby the latter was reduced once more to the original chalk, or rather to chalk in the condition of chemically pure monocarbonate of lime, which was insoluble, and was thus precipitated in the softening process. It was vital to the softening process that the extra carbonic acid in the soluble bicarbonate should be got rid of for reducing it to the insoluble monocarbonate.

With respect to the wear of the filter cloth (page 64), he enquired whether it might not be the case that its destruction was largely accelerated by the presence of sulphate of iron in the water, derived from iron pyrites occurring in the chalk.

With regard to the taste, he was himself able to answer Mr. Marten's question (page 64), because he had tasted the water as it came from the tank, and found it delicious. There was nothing disagreeable at all, not so much as a flavour of any kind that could be objected to. It seemed to him surprising that other towns had not adopted the same process, for it had been a revelation to

(Mr. Charles Cochrane.)

himself to visit these works at Southampton and to see the result produced by the softening process. All who had had any experience of the water in the south of England—at Brighton and Folkestone, for example—where the water was supplied from the chalk, must have found it so hard as to be really most disagreeable to use for washing in. The excellent example set by Southampton in this matter was one which he hoped would soon be copied more generally.

Mr. William Schönheyder noticed that in the description of the fly-wheel shaft (page 56) it was stated that the journal in the outer plummer-block was 9½ inches diameter, whereas in the inner it was 12½ inches diameter. As a rule he thought it was well to make the outer journal the same diameter or thereabouts as the inner, not for mere strength but in order to carry the weight of the fly-wheel, and to work without getting hot. The fly-wheel bearing differed from a crank-shaft bearing; the load on the former being always downwards, the oil had less chance of getting in than in a crank-shaft bearing, where the journal was lifted up and pressed down alternately. In several cases of that kind he had known bearings get hot on account of insufficient bearing surface; and he enquired whether anything of the sort had occurred in these engines, and what was the weight of the fly-wheel.

The whipping of long pump-rods he had seen frequently; but he did not agree with the remedy which had been applied, of adding rollers to stop it (page 57). There were two sets of rollers on each rod, three to each set; and as the rollers themselves turned on their pins, there were altogether six bearings working in water quite out of sight, which seemed to him an undesirable arrangement. They might go all right for a long time, but might suddenly go wrong and take to grinding and cutting the pins through; and if a roller were to drop down the pump it would be a serious matter. A much simpler plan, and one commonly adopted, was to provide a guiding cylinder, connected by arms to the pump-rod, and keyed or fastened upon it to work up and down inside the pipe; the inside of the pipe need not be bored; and if sufficient clearance were allowed, both the guiding cylinder and the pipe would last for a long time. The plan was simplicity itself, and nothing could go wrong; he should himself much prefer it to rollers.

These engines having been erected so recently, he was rather surprised to find that the steam-pressure was not higher than 60 lbs. per square inch. As they were compound engines, he thought it would have been more economical to have 70 or 80 lbs. pressure, or perhaps even more. The works being situated so far out of Southampton, it seemed to him there would have been plenty of space for the hard-water delivery pipe from the low-lift pumps to the softening apparatus to be laid round the outside of the building. For although a symmetrical arrangement was obtained by carrying it along beneath the centre line of the building, yet the cost of building the tunnel over it and of getting at the pipe at any subsequent time must be something considerable. If it had gone round outside the building, much expense might have been saved in that way, and might have been better employed in jacketing the intermediate receivers and any other parts which were not jacketed in the engines.

Mr. Robert B. Buckley, having been engaged as an engineer in India, said that until recently the construction of water works in that country had hardly been undertaken. There had been water works in Calcutta and Bombay for many years past; but throughout India generally he thought that ten years ago there were no water works at all. Now however a great advance was being made; water works were being constructed in many of the large towns, and in the course of the next few years there was no doubt that they would be largely increased in number. One of the great difficulties to be dealt with in India arose from the fact that the rivers from which the water supply was generally drawn, although very clear indeed for eight or nine months of the year, became most densely charged during the floods or rainy season with extremely fine muddy matter in suspension. So much was this the case that at the Calcutta water works enormous settling tanks had to be used for enabling the supply to be maintained at all at such times. For about a fortnight

(Mr. Robert B. Buckley.)

at the worst time, at the end of August, the water was allowed to settle in these tanks for four or five days, and was then run through ordinary sand-filters. At times the greatest difficulty was found in keeping up the supply at all. For although the water was allowed to settle for so long as four or five days, the filters nevertheless became completely choked in the course of a few days; they became indeed so absolutely water-tight that they had to be run dry, and their surface had to be scraped off, before any more water could be got through at all. The difficulty it was true lasted only for a short time; but it added of course to the cost of the water works that such large settling tanks and such large filtering power had to be provided for meeting this occasional difficulty. He asked therefore whether it would be possible for the method of filtering described in the paper to be employed for clearing those Indian waters of the extremely soft and fine mud which they held in suspension; and whether any idea at all could be given of what the cost would be, say per thousand gallons discharged a day; or any data for determining whether these filters would be more economical than the large settling tanks and sand filters now used.

As to the cost of pumping, which was given at 0·634 penny per thousand gallons (page 58), he asked what was the height of lift of that quantity of water, and also what was the price of the coal. Both of these were factors which entered largely into the cost of the work done.

Mr. Charles E. Cowper asked how long the filter cloths would run without cleaning; and also the length of time that they would last before having to be replaced. If it could further be stated what was generally the cost of filtering on the plan described in the paper, this information would be of value.

Mr. Jeremiah Head, Past-President, as one of those who had enjoyed the opportunity of visiting the water works at Southampton last summer, was glad to express his own high appreciation of the establishment as a whole. It seemed to him to be excellently laid out and constructed, and a great credit to all those who had had to do with it. In the importance of the filtering arrangement he quite agreed with what had been said by Mr. Cochrane (page 68). The time was certainly more and more nearly approaching when in this country and in all densely populated countries it would be necessary to use every water-supply that could be got from anywhere, for the benefit of the increasing populations. A large quantity of the available water-supply came from limestone districts, and was consequently hard, being charged with bicarbonate of lime in solution in the way that had been described (page 67). It was to such water that the softening process used at Southampton was peculiarly applicable. There were also other waters which were hard from containing in solution sulphate of lime or gypsum. Those were the waters which were so much appreciated by brewers; and the existence of the great breweries at Burton-on-Trent was said to be due to the circumstance that the water procured from the wells there was charged with sulphate of lime. The lime process however, described in the paper, would not be applicable he thought to softening that kind of hard water. As employed at Southampton it seemed to be admirably applicable; and of course its great virtue lay in its compactness. Although the Southampton water works were well outside the town, the land they occupied had no doubt to be paid for; and it was therefore desirable for all the operations to be performed in as small a compass as possible. There were many other places where even so much space would not be available as at Southampton, and where with the same kind of water the softening process would be not less acceptable, especially if it could be carried out in a comparatively small space and for so small a charge as at Southampton. The compactness of the softening arrangements appeared to himself therefore to be a highly important feature of the process.

In the trials of the engines (page 59) he noticed that the coal consumed was in one 1,757 lbs. and in the other 1,750 lbs., while the ashes made were only 14 lbs. and 15 lbs. respectively, or considerably less than 1 per cent., including clinkers he presumed. The coal must therefore have been of remarkably good quality; in fact almost too good to allow of forming an approximate idea of what might be expected if ordinary coal were used.

(Mr. Jeremiah Head.)

In these pumping engines he did not quite understand why massive cast-iron beams had been adhered to, and why they should not have been made of steel, either as steel castings, which were now turned out on so large a scale, or of steel plates built up. Steel beams would certainly be much safer than those made of cast-iron. It was true the latter did not often break; but all would remember the fatal accident at the Hartley Colliery in Northumberland (Proceedings 1863, page 265), caused entirely by a cast-iron beam breaking in two, and one end of it falling down the pit, producing so terrible a disaster. Considering that the difference in cost was so little, inasmuch as the steel beams might be made so much lighter, he could scarcely understand why the risk, which at all events did still attend the use of cast-iron beams, should not be eliminated by making them either of steel castings or of steel plates built up.

Mr. Henry J. Coles had had some experience in the construction and working of the class of cloth filters described in the paper. Dr. Clark's process for softening hard water, of which there was a good example at the Herbert Hospital, Woolwich, was the fore-runner of all attempts to attain this object. The cloth filters had been introduced in order to do away with the large amount of ground area occupied for filtering on Dr. Clark's original plan; but there was this difference between the two, that whereas in the Clark method of filtering, although a large area was occupied and the work of moving the stirrers was rather heavy, yet the most ignorant class of labourers sufficed for it, so long as they were given the right quantity of lime to use. In these cloth filters there was no doubt that the cloth made a good and handy filtering medium; but the plan of putting it on discs, as was done at Southampton, did not appear to him to be the best. The discs, when they were being put together again after they had been taken apart, had all to be threaded on one spindle; and there was often a difficulty in making the joints water-tight: so that it was apt to be found afterwards, unless experienced labour had been employed, that there was one joint defective, and the whole had to be taken to pieces again. Another objection was that often the chains or slings used for putting the discs into their places in the filtering tank would scratch a piece of the cloth; and the whole had then to be taken out for replacing the damaged cloth. Another feature that he thought engineers did not generally approve of was the large stuffing-box, in which the disc-shaft had to revolve every time the discs were cleaned. The method of cleaning by the use of the water spray was no doubt a distinct advance, because by its adoption all necessity for the use of mechanical power for cleansing a suitably designed filter was entirely obviated. The earlier designs of filters had been made with bristle brushes and india-rubber brushes, with the result that, though the outer portion of the coating of deposit was removed, the inner portion was rubbed more thoroughly into the cloth. In the design of the filter it was highly advisable to have each disc or filtering bag entirely independent of the others, so that it could be removed without in any way affecting the action of the rest of the filter, and therefore any defect in one part would not necessitate total dismantling. For small installations a good plan he thought was to have a plain oblong linen bag placed inside a thin perforated metal envelope, dropping into a tank as many of these as might be needed. Being oblong they fitted into an oblong or square tank, and offered more filtering surface than a circular bag or disc. For jointing the bags to the hard-water supply, all that had to be done was to have a cap over each bag, and let the hard water trickle through it into the bag; then for the process of cleaning or for repairs it was necessary only to remove one at a time of these bags with its envelope, which must be stiff enough to support the bag. By simply removing the bag to be cleaned and replacing it by a fresh one, the cleaning could be carried on without interrupting the filtering operation. Moreover when the bag was taken out it had simply to be turned inside out and washed, and was then ready to be replaced; there was no trouble about by-passes, or sediment in the bottom of the filter tank, because into the tank itself nothing but filtered water flowed; all the sediment was intercepted inside the bags. For large installations the cloth should be outside the metal frames, and the water spray so arranged that it would sweep the whole surface of the cloth. Each of the filtering bags should be entirely independent of

(Mr. Henry J. Coles.)

its fellows, so that it could be removed for repairs, and if desired another be substituted without stopping the action of the filter. On this plan filters could be made of any capacity, the labour of cleansing being only equal to that of cleansing those described in the paper, and the use of mechanical power for rotating the discs being entirely obviated. The filtration of the turbid softened water was necessary not merely for the sake of clearness, but also on account of the chemical action mentioned by Mr. Cochrane (page 67); for if cream of lime was simply put into an open tank with hard water and the precipitated carbonate of lime was allowed to settle to the bottom without being removed by filtration, and the water was left exposed to the atmosphere, it would absorb a certain amount of carbonic acid, and after a time the water would become hard again. As to the reason why the Clark process of softening had not been more largely adopted, he believed that about thirty years ago some of the water companies tried it on an extensive scale; and he understood that some of the largest companies were quite prepared now to adopt it, if some good mode could be suggested for getting rid of the carbonate of lime taken out of the filter, without having to pay for cartage. Various attempts had been made to attach a commercial value to the precipitate: it made good tooth-powder, and had also been used as a vehicle for absorbing disinfecting acids; but the cost of drying it was too great, and, even had it been otherwise, the demand was too small to dispose of the large quantities of precipitate which would accumulate. Doubtless however, could any method of using it be devised to cover the cost of its removal, many large corporations would be prepared to adopt water softening.

Mr. JOHN BARR, being unable to attend the meeting, wrote that he had enjoyed the privilege of seeing these engines at work on occasion of the visit to Southampton in July last. The bucket and suction valves of the low-lift pumps he noticed were stated (page 57) to consist of double india-rubber valves working against cast-iron guards and grids; was there no trouble from corrosion of the grids and guards? Did the level of the water in the well vary much? if so, did not this give the engine more work to do on the low-lift side than on the high-lift or delivery side, and tend to throw the engine out of balance? What arrangements were made for keeping the air-vessels charged with air?

The buckets of the low-lift pumps were stated to be of cast-iron and water-grooved, but without packing or rings. Had it been ascertained whether these grooves served any good purpose? or did they act as receptacles for grit? In experiments made by himself some time ago at the Glenfield Works, Kilmarnock, to test the effect of grooving a solid brass piston which was made a good working fit in a mandril-drawn brass tube of 1¼ inch bore, the leakage in half an hour under a head of 150 feet of water was as follows:—

Solid piston without grooves	2·22 lbs.
Same piston with two grooves	5·72 lbs.
Do. with two gutta-percha rings slack in grooves	4·41 lbs.
Do. do. tight in grooves	None

How many pounds of water were evaporated in the Lancashire boilers per pound of Welsh coal? and in actual daily work what was the coal consumption per indicated horse-power and the efficiency of the engines?

Mr. EDWARD M. EATON, Engineer of the Sheffield Water Works, wrote that it would be of much interest if the author could give the total cost of lifting a thousand gallons of water through a hundred feet height by the Cornish and rotative engines respectively at the Mansbridge works. The difference in coal was 0·2 lb. per I.H.P. per hour in favour of the Cornish engines; was this balanced or more than balanced by the saving in attendance &c. on the rotative engines? It was not often that both kinds of engines were at the same place and doing the same work.

Mr. E. H. G. BREWSTER remembered that some years ago the late Mr. Robert Briggs, a well-known American engineer—who had made trials extending over some period of water packing for the pistons of pumps, the pistons having a number of grooves turned in them—had stated that, although the arrangement was effective, there was a considerable amount of friction in connection with its use, and he did not employ it on that account.

The PRESIDENT thought that, with respect to surface condensers giving a taste to the water (page 64), experience showed they did not do so. Indeed even when the contents of the hot-well in engines with jet condensers were discharged into the water, they did not give any taste to it, unless the users happened to know that it had been so treated. He had done this twice himself, and knew of two towns in which it was still done; but he would not mention their names, because if it once got abroad the inhabitants would immediately fancy that the water tasted of oil. The quantity was relatively so small that he thought it could not produce any effect whatever upon the water.

The class of engine that had been adopted for the pumping station at Otterbourne was one of which he could not too strongly express his approbation, including the low pressure in the boilers. From considerable experience he believed there was nothing like a good heavy slow-running beam-engine to work regularly and steadily year after year, requiring scarcely any repairs. This, after all, was one of the most important considerations in the water supply of a town. The tendency now-a-days, he thought, was pretty nearly universal to adopt fast-running engines working at high pressures; but the repairs he was certain would prove heavier than those of engines of the older kind working with about 60 lbs. pressure of steam. These slow engines he had known to run for eight or ten years or longer without any general overhaul; an occasional adjustment of the brasses had been quite sufficient to keep them in perfect order. The use of cast-iron beams, referred to by Mr. Head (page 72), was certainly advantageous in view of the circumstance that the weight of a beam was an element in the smooth running of an engine. The momentum of the beam and of the other moving parts in an engine working expansively was an important factor in getting the engine to work smoothly: the excessive pressure in the cylinder at the beginning of the stroke was taken up in getting the beam into motion; and when the pressure diminished towards the end of the stroke, the inertia of the beam helped the forward movement, and produced smoothness of running, which could not be got in light engines. Having himself made engines with beams of steel plate as light as they could be made, he had never found them run so smoothly and so well as engines made with heavier cast-iron beams. Although of course it must be admitted that cast-iron was liable to serious internal stresses, which might render an engine beam of that material liable to break, he could not recall a single instance of a pumping engine in which an accident of that kind had happened, except the one alluded to by Mr. Head (page 72). No doubt other such accidents had happened, but he did not know of them.

With regard to the turbid water of the floods in Indian rivers (page 69), settling ponds were hardly necessary, if at the periods mentioned by Mr. Buckley the water were treated with iron, either on Bischof's plan, or on the plan which he had himself introduced, at Agra for example, where the water was passed through a revolving cylinder, in which it was made to mix with iron in a state of scrap, of punchings or borings. Iron had an extraordinary effect upon water; it seemed to be a sort of coagulating effect. The sediment in the Indian water, which was so exceedingly fine that it could scarcely be filtered out absolutely clear without leaving some opalescence, appeared to curdle together, much as isinglass made brewers' liquors clear or as white of egg clarified a jelly. When so treated, the water filtered easily through a few inches of sand, and the filtering could go on for a long time without cleaning the filter, chiefly because the sediment deposited on its surface was in a much coarser state, not so slimy as when it was attempted to filter the water in its natural state, before treating it with iron. The water of the Nile, for example, in which the sediment would not subside in any reasonable time, certainly could not be filtered by any sand filter; and though it could be filtered by porous earthenware, yet that was an extremely slow process and impracticable on a large scale. If however, it were kept in contact with iron for three minutes, it would filter absolutely clear through an ordinary sand-filter with only about three inches' thickness of sand. When there was dirt in the water, it must of course be removed; and whether settling ponds or filter beds were used, the dirt must be scraped out of them or off them.

(The President.)

It was rather singular that the application of Dr. Clark's process of softening by the addition of lime to hard water, though it had been known for so many years, had not been more generally adopted for existing waterworks. One of those which were still behindhand in this respect was the Kent works, whose water he had the misfortune to be obliged to use. Their wells were in the chalk, and they could get a supply of lime with the greatest possible ease and economy. The cost was so small that it was surprising they did not set about softening the water for the benefit of their large area of customers. Indeed it seemed a wonder that any waterworks deriving their supply from the chalk were not compelled by law to soften their water, in order to make it fit for domestic use. No doubt the author had studied this subject with a view to deciding which plan of treatment after softening should be adopted: whether the system of having extensive settling ponds or reservoirs, or the process of separating the sediment mechanically; and which of the two would come out the cheaper in capital outlay. The one carried out at Southampton required machinery, but only a certain small extent of tank or reservoir accommodation; in the other, which had been successfully in use at Croydon for many years past, the whole clarification was done by allowing the sediment to settle in large tanks.

Mr. MATTHEWS, in reply to the enquiries (pages 63 and 70) as to the lift of the pumps, said that at the trials the total lift of the high-lift pumps was about 160 feet, and of the low-lift pumps about 58 feet. With regard to the hardness of the well water (page 64), the pumping had now been continued for 3½ years without any difference having been found in the hardness of the water. Originally it had about 18 degrees of hardness, when drawn from the trial borings, and it was practically the same now: each degree corresponding with one grain of carbonate of lime in one gallon of water, or 1-70,000th part by weight. At some stations it had been found that after a while the hardness had become slightly reduced; but it was not so at Otterbourne. The boring of the two wells (page 63) had been described in a paper he had read before the Institution of Civil Engineers (Proceedings 1887, vol. xc, page 33);

they were 6 feet diameter, and were both of them bored out in a single operation without the intervention of any pumping. Originally the intention had been not to line the borings at all, as it had been thought the chalk would be sufficiently hard to stand; but that had been found not to be the case, and they had afterwards been lined with perforated steel tubes.

By the whipping of the bucket rods (page 64) he wished to express the fact that in the low-lift pumps, when the water was at its lowest in the well, and there was such a long length of suction to pump through, the rods being rather light were so elastic that originally they vibrated laterally to a considerable extent, though not enough to touch the sides of the pipe, and the keys were not knocked out. Apparently the rods had also a tendency to twist, corkscrew fashion, at the same time. The guiding rollers subsequently added had been carefully designed and strongly made, with a view to preventing any risk of their going wrong (page 68).

The question of the taste of the water (page 64) had already been dealt with by the President (page 76) and Mr. Cochrane (page 67). No difficulty had been experienced in regard to the taste of the water from its being passed through the surface condensers. As to the chemical difference in the water before and after softening, an analysis made by Dr. Frankland showed that in 100,000 parts the ammonia was 0·005 before and 0·004 after softening; the nitrogen, contained in nitrates and nitrites, was 0·365 before and 0·381 after; total combined nitrogen 0·381 before and 0·397 after softening; chlorine 1·6 in both cases. So that there was practically no difference between the water before and after softening, beyond the all-important difference that the carbonate of lime had been reduced from 23·93 in the well water to 5·67 in the softened water, whereby the hardness of the water had been reduced from 18 degrees to only 6. It was possible indeed to reduce the hardness still lower, down to only 4 or 3 degrees; but the water then became flat and insipid, and was not much appreciated in a non-manufacturing town like Southampton.

The duty of the engines had been calculated (page 64) not from the theoretical displacement of the pumps, but from their

(Mr. Matthews.)

actual displacement obtained by deducting their ascertained slip of 2·73 per cent.

The duration of the cotton filter-cloths (page 64) had been rather variable; and it had been a long time before sufficient experience had been gained to know how it was that at some times the cloths wore out quickly, while at other times they lasted as long as seven or eight months. Their quicker wear could hardly be due to the presence of sulphate of iron in the water (page 67), as but one small nodule of iron pyrites had ever been found in the chalk quarry. Eventually, almost by accident, the reason was discovered. It so happened that at a time when there was a great deal of trouble with the cloths it became necessary to start driving the headings again, in order to obtain a greater yield of water. In the process of driving, a large quantity of chalk from the lowest depths was brought up to surface, and instead of being thrown away it was taken to the kilns, and when softening was resumed after completing the headings it was burnt into quicklime; and it was found that the best result with the cloths was during the time that this chalk from the headings was being used. On further investigation it was found that the reason was nothing but the absolute purity of the chalk obtained from those lower depths. Since then no more lime had been burnt from the upper layers of chalk, which were somewhat stained with infiltration of clay from the surface; and much better results had been obtained with the filter cloths than before. The earlier filters put up on this plan had been arranged, as had been mentioned (page 73), for cleaning off by brushes the sediment deposited on the filter cloth; and there had also been a scheme for injecting water at high pressure into the interior of the disc shaft, so that it might pass out through the perforated zinc and the filter cloth, producing an outward flow with the object of washing off the deposit in that way. But the effect of the outward current was found to be seriously to distress the cloth by lifting it off the zinc disc; it became extended, and its elasticity was so far destroyed that it never returned to its original condition; the pores were much opened, and its efficiency as a filtering medium was absolutely ruined. Later on it was found by

Mr. Atkins that steaming the filters (page 66) was a good plan; and now, instead of injecting water into the apparatus, the pipes and valves were utilized for injecting live steam from the boiler at times, giving the cloths a thoroughly good boiling. It was found that a certain proportion of the deposit did get worked into the cloth, and was held there so firmly that no amount of water spray applied externally would get rid of it; but by passing live steam through from the inside at only 5 or 6 lbs. pressure per square inch the deposit which had been arrested in the pores of the cloth got driven out, giving the cloth a much longer duration. With proper usage he thought the life of a cloth might be safely taken to be from five and a half to six months. When it was necessary to renew the cloths (page 65), the hollow shaft with the twenty discs attached could be lifted out bodily by means of the overhead traveller, and the spare shaft and discs, which were always kept prepared in readiness, could be put in its place; the whole operation took less than an hour, and with proper lifting tackle, such as was used at these works, no possible damage such as had been suggested (page 72–3) could be done to the cloths. As to whether the filtering was more rapid and efficient at first than it was at a later period of the operation (page 65–6), that was true to a certain extent; but the efficiency of the filtering did not depend absolutely upon the cloth. Indeed it was not considered that the cloth itself really filtered the water at all; it simply acted as a framework, upon which the small crystals of carbonate of lime were deposited; and when they had collected upon it, they themselves acted as the filtering medium for the water that came afterwards. After the filters had been cleansed, some of the carbonate of lime, as had been suggested (page 65), got washed inside the discs; and when the unfiltered water was first turned on to the cloths, some of it would pass through them without undergoing filtration, until there was built up on the outside the first collection of crystals of carbonate of lime. There was an arrangement of valves and pipes, whereby, for about a minute or a minute and a half after the unfiltered water had been turned into the filtering tank, the water which first passed through the filter did not go into the softened-water tank but into the waste pit, until there was a sufficient

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deposit of carbonate of lime on the outside of the cloth to make a perfect filtering medium. The softened water drawn from the filters was thus obtained of equal purity during the whole time. The only variation was in the quantity; the quality did not vary, but the quantity passing through the filters was perpetually varying. There was the same head of water constantly maintained on the filters. After a while there was of course a larger deposit of carbonate of lime on the faces of the discs; and then the filter began to discharge water into the softened-water tank much less quickly than it did at the start. The orders given to the attendant were that when a filter had collected a certain amount of deposit it must be cleansed; and he had to keep the water up to the same height in the filter tank, just as over filter beds the water had to be kept to the same head. If the filters were allowed to go too long, till the cloths got clogged, the flow of water would be entirely suspended. But of course it would be understood that in practice the filters were cleansed in rotation, without waiting till the cloths got clogged. According as they had been a longer or shorter time in use, the attendant was soon able to judge as to the time when the filters should be cleansed. When the cloths were new they would go on an average about nine hours without cleaning; later on, when they had about lasted their time, they would only go about six hours. Carbon blocks (page 66) had never been tried at Southampton, where there had never been any other arrangement than that of filter-cloths; he had heard of carbon blocks having been tried in some places, but he did not know how they had acted.

The outer bearing of the fly-wheel shaft (page 68) had given no trouble whatever. The inner bearing, nearest the crank, which was the larger of the two, had done so. It would be noticed that, owing to the character of the foundations, although the inner bearing nearest the crank was on brickwork, lower down the brickwork had to be supported on a short girder in order to make room for the pump; and that girder had apparently taken a little permanent set, and let the plummer-block down a little, and the crank-pin ran a little warm; the plummer-block had to be packed up with a steel liner 1-32nd inch thick, and after that had been done the brass did not heat. With that exception there had been no trouble at all with the bearings. The weight of the fly-wheels was ten tons each, and for the size of the engines they were comparatively light. Even if the whole weight came upon the outer bearing, which it did not, the pressure per square inch would be only 182 lbs.

As to the reason for adopting only 60 lbs. pressure of steam (page 69), the President, who had had so much more experience than himself, had already given a sufficient reply (page 76). These were slow-moving engines; and engineers who had had to do with pumping water for many years would admit that a slow-moving engine with a long stroke was much better and easier to deal with from year's end to year's end than a fast-running engine. The engines at Otterbourne had now been going about three years and a half, and practically not a farthing had been expended in repairs. There had been no replacing of any single portion up to the present time, except the india-rubber suction and air-pump valves. No metal work had had to be touched, nor did it seem likely to require any touching for a considerably longer time.

The well-water pipe from the low-lift pumps to the softening works was purposely laid under the centre of the building (page 69), because in that position it led away symmetrically from the two low-lift pumps; and moreover an arrangement had to be made as shown in Plate 13, just under the repairing shop, for getting by-passes into the two softened-water pipes leading to the high-lift pumps: so that, if in any emergency the softening works had to be put out of gear, the hard water could be pumped round from the low-lift pumps direct to the high-lift. It was a mere matter of arrangement. The tunnel was of course somewhat expensive in the first instance; but the pipe laid in it could always be got at, and in case of building another engine-house, already contemplated, there would be no difficulty arising from mains being in the way.

In regard to dealing with muddy water like that in Indian rivers in time of flood (page 69), there had on one occasion been an opportunity of practically testing whether the Otterbourne works would deal with muddy water. In extending some of the headings at the bottom of the wells, it became a question whether temporary

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pumps should be put down, and the water be shut off which would be rendered turbid by the men working in the headings; or whether the turbid water should be pumped up and passed through the filters, the softening apparatus being suspended for the time. The latter plan was tried; but after the explanation he had already given as to how the crystals of carbonate of lime acted in forming a filtering material, it would be understood that the chalk, in the amorphous condition to which it had been reduced by being trampled upon in the headings, was not in a similar crystalline condition, but in the condition of mud in a river; it therefore collected on the faces of the filtering discs at once, and in half an hour they were so completely blocked up that nothing could be done with them until the mud was washed off. For filtering muddy water therefore it was evident that to keep washing the filters every half hour would be rather too much of an undertaking; and not only so, but there would be a considerable expenditure of water for washing. A scheme he believed was being worked out by Mr. Atkins, whereby the filter cloth was arranged in such a way as to be constantly moving over rollers, so that in some fashion it could be used continuously for filtering and at the same time could be washed continuously. No doubt if that was possible it would be found practicable to accomplish it; and then there would be no reason why the cloth should not form a filtering material for muddy water, if it could be cleansed almost immediately.

In regard to the application of the softening process to other water than chalk water (page 71), the most noticeable instance in which it had been so used was at Wellingborough in Northamptonshire, where it was employed for softening extremely hard water, having about 37 degrees of hardness, and highly impregnated with iron. The only question in a case like that was the quantity of lime to be used; and in that instance not only was the hardness removed that was due to the bicarbonate of lime dissolved in the water, but the iron with which the water was also impregnated was thrown down with the lime, and the water was rendered beautifully clear. The sulphates (page 71) were not removed in that case, for the simple reason that the attempt to remove them would have involved the necessity of going beyond the use of lime, and using other chemicals which were afterwards objectionable in the water for domestic purposes. If the water were going to be used only for feeding boilers or for certain manufacturing purposes, there was no reason why the sulphates should not be thrown down by the use of caustic soda or some other re-agent, the water being afterwards filtered in the same way as at present; but whether that would have any injurious effect on the filter cloth, he was not prepared to say.

The cost of softening generally at other similar works (page 70) varied from 0·79 penny per thousand gallons at Wellingborough, where the water had 37 degrees of hardness, to 0·34 penny at Henley-on-Thames, where the hardness was 21½ degrees.

The total space actually occupied by the softening works (page 71), exclusive of the pumping works, was only 1,150 square yards. As had been remarked (page 69), the Otterbourne works were situated at a distance of about eight miles from Southampton, so that the question of an acre or two more of land was not of much importance. But although plenty of land had been obtained all round the works, there was no reason to extend them. They had been laid out on a sufficiently large scale for enabling every part to be got at conveniently; but there was really no reason why the space occupied should not have been even a little less ample than it was, if it had been necessary for the works to be got into a more confined area.

The alleged difficulty in making the joints water-tight (page 72), between the filtering discs and the intervening collars threaded upon the hollow disc-shaft, was entirely a question of whether the work had been properly executed in the first instance. If the collars were turned as well as they ought to be, so as to have good true faces, they should be perfectly interchangeable, and there should be no risk of any difficulty arising from getting a wrong collar in a wrong position between the discs. That was entirely a mechanical point, dependent upon having the work done as it ought to be. At Otterbourne no difficulty at all had been experienced in that respect. The practice was to put between each collar and disc a piece of filter cloth, which at first had always been coated with paraffin wax; but it had

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since been found that there was no occasion for any waxing whatever. When a plain piece of cloth was put in between, in less than half a minute there was a sufficient collection of carbonate of lime over it to make as water-tight a joint as could be wished. Nor had there been any trouble with the stuffing-box (page 73), through which the disc-shaft came out at the front end of the filter tank, so as to allow the shaft to revolve. Good care had been taken in designing the stuffing-boxes that they should be of a suitable construction; and they had not given any trouble at all. Some of the earlier works of this kind he believed had been put up probably a little cheaper than they ought to have been; and any of the difficulties which had occurred with them had probably arisen from that cause. But with proper attention to the mechanical details he was convinced there need not be any difficulty whatever. From his own experience he should be sorry to attempt to deal with anything like 2 or 2½ million gallons of water per day by filtering it through the bag and envelope arrangement suggested (page 73). With an apparatus of that kind, of anything like a reasonable size for such requirements, he had not had the opportunity of calculating how many bags would be required of a size that could be handled satisfactorily by one man; but it might readily be understood that the manual labour involved in actually taking the bags out for the purpose of washing them, and then putting them in place again, would be something enormous. It was practically labour of that very kind which had proved fatal to Mr. Porter's original plan; in his method there had been at first really the same arrangement of using filter cloths upon fixed frames, which were put in a trough and had to be removed by hand labour. Another arrangement had now been substituted, because it had been found that the labour involved in so dealing with large quantities of water precluded the original plan from being used.

The disposal of the waste deposit from the filters was of course a serious question (page 74); and no doubt the softening process would be adopted much more extensively, if a market for the waste could be found. At Otterbourne all sorts of directions had been tried; but at present he was sorry to say it was still necessary to discharge as waste, into an old quarry which had been acquired, what possibly might, if a proper use could be found for it, prove to be a valuable by-product. A quantity of it had been offered to the cement makers to experiment upon, in order that they might see whether it was not a material which was practically in a form almost ready for their use; but unfortunately they seemed to hesitate even to give it a fair trial.

The PRESIDENT supposed it could not be converted into lime again by burning in a kiln.

Mr. MATTHEWS said that unfortunately it was in a state in which it was difficult to deal with; it was so dense and heavy that it would almost want moulding into blocks, so as to be able to keep the kiln open and get the draught through it. In the state in which it came from the filters it was found that it killed the kilns altogether.

In reply to Mr. Eaton's enquiry (page 75) about the relative cost of pumping by the two pairs of engines at the old Mansbridge works, the lift was identical and the attendance was identical in both. They both lifted 200 feet, and there was one attendant required in each engine-house: so that the difference in cost of pumping could be almost exactly calculated from the total quantity of water pumped per day and the coal consumption, as given in the paper.

There had been no trouble from corrosion of the grids and guards of the suction valves (page 74). Although they were made of cast-iron, it was found that with the hard water from the wells all the iron work after a short time became coated with a fine enamel, almost as good as a white enamel; and there had been no trouble from corrosion of any sort.

The level of the water in the wells (pages 63 and 74) varied of course considerably with the pumping; and after pumping say twenty-four hours from starting, the water would be 35 or 40 feet lower in the wells and headings. The engines would certainly be somewhat out of balance when pumping from any other level than the normal for which they were designed; but the variation of level was small, probably not more than five feet either way, inasmuch as

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pumping was continuous day and night, including Sundays. There was an air-charging arrangement of the usual kind for charging the two air-vessels, which was worked off the same cross-head and rods that actuated the air-pump.

With the water-grooves in the buckets of the low-lift pumps there had not been any trouble (page 75); and the double-acting plungers of the high-lift pumps were also grooved upon the same plan. The grooves were semicircular, 5-16ths inch diameter and 6 inches apart. In arranging what kind of packing to adopt, it was necessary to have regard to the nature of the water that was being dealt with. If it were sandy water, and there were any liability of bringing up sand with it, the use of water-grooves would probably be out of the question, as the sand would score the working barrels all to pieces. But the pumps had already been drawn two or three times, and the barrels showed hardly any sign of wear at all at present. What was the amount of friction due to the water-grooves he did not know; but judging from the comparatively high efficiency of the engines generally, he thought the friction could not be anything considerable. The leakage or slip of the pumps altogether was only 2·73 per cent. in the trials, as actually measured by pumping into the reservoir with the outlet closed.

The suction bucket in the low-lift pumps (page 63) was situated down at the bottom of the well, as close as it could be got to the foot-valve, so that at the very beginning of the pumping stroke there was only just sufficient clearance above the foot-valve. The plunger portion of the low-lift pumps was higher up, at the top of the well; and the bucket was hung from the plunger by the long rod which was steadied by the roller guides.

In the trials of the engines (page 59) the coal used (page 71) was Nixon's Navigation, hand picked; and great care had been taken in stoking and in working generally, in order to obtain the best possible result. In regard to the efficiency of the engines in every-day work and the water evaporated and the coal consumption (page 75), with coal from the Powell Duffryn Colliery the consumption in ordinary work was about 2¼ lbs. per hour per actual horse-power in the water lifted, the slip of the pumps being from 4 to 5 per cent.

The engine efficiency was about 82 per cent.; while the consumption of feed-water per hour was $21\frac{3}{4}$ lbs. per actual horse-power, or $17\frac{1}{2}$ lbs. per indicated horse-power.

In reply to the question asked by the President (page 78) as to the capital outlay required for the two processes of filtering—by settling ponds or reservoirs, or by mechanical filtration,—the relative cost had been worked out at the time when it was being decided what kind of arrangement should be adopted at the Otterbourne works. The first cost of the original Clark process with settling ponds, which was adopted at Croydon, would have been about £3,000 more than of the present mechanical filters at Otterbourne, exclusive of the cost of the extra land required for the large settling ponds.

The PRESIDENT was sure the members would wish to accord a hearty vote of thanks to Mr. Matthews, first, for having been so good in showing them all over the works when they visited Otterbourne last summer, when many of those present had been so glad to take advantage of his kindness; secondly, for the paper which he had prepared for their information; and last, but not least, for the complete manner in which he had answered all the questions put to him in the discussion.

MEMOIRS.

ROBERT JAMES CROSS was born on 22nd April 1841 at Farm Easton, Chagford, near Exeter, and was educated at the Ayton Quakers' boarding-school. At the age of fourteen he was apprenticed for seven years to Mr. Dicker, millwright, at Chagford; and on completing his time he went to Birmingham, and thence to Sydney, New South Wales, to join the Illawari Steamship Co. as second engineer on their vessel the "Illagory." In 1867 he returned to England, and soon afterwards went out to New York as engineer on board a steamship. Subsequently he entered the service of Messrs. Thompson and Boyd, Newcastle-on-Tyne, as outdoor foreman of their engineering works; and on leaving them became superintendent to Messrs. Watts Milburn, steamship and colliery owners, and subsequently superintendent engineer to the then firm of Messrs. Burns, steamship owners. He left there in 1873 to join Messrs. Mark Whitwill and Son, managers of "The Great Western" steamship line, Bristol, as superintending engineer; and served simultaneously in the same capacity to the Wapping Dry Dock Co. With the latter firm he remained until 1881, when he resigned this position in order to devote his whole time to Messrs. Mark Whitwill and Son, with whom he continued altogether for twenty years. His death took place at Bristol on 4th February 1893, in the fifty-second year of his age, after a long illness. He became a Member of this Institution in 1890.

HENRY JOHN SILLARS DÜBS was born on 27th April 1848 at Newton-le-Willows, Lancashire, being the eldest son of Mr. Henry Dübs of the Glasgow Locomotive Works (Proceedings 1877, page 18). Having been educated in Scotland and in Germany, he served his apprenticeship in his father's works, in which he became a partner in 1876, and with which he continued to be identified up to the time of his death, which took place at Glasgow after a long illness on 5th April 1893, in the forty-fifth year of his age. He became a Member of this Institution in 1877.

Francis Holt was born at Todmorden on 5th December 1825. After serving his apprenticeship with Messrs. Sharp Stewart and Co., Manchester, he remained with them for some time as foreman, and went thence to Woolwich dockyard. Afterwards he was engaged in Italy on the construction of a railway at Pisa; but in consequence of the stoppage of that undertaking he returned to England, and had charge for about a year and a half of the locomotive department of the South Staffordshire Railway at Walsall. He next went out to India, to erect and fit up a cotton mill for the Oriental Spinning and Weaving Co., Bombay, and remained there three years. Returning to this country he became manager for some years at Messrs. Beyer Peacock and Co.'s locomotive works, Gorton, Manchester; and then manager to Messrs. R. and W. Hawthorn, Newcastle-on-Tyne. In 1874 he left there to undertake the managership of the Midland Railway locomotive works at Derby, where he remained up to the time of his death. During his connection with these works they underwent large extensions, in which he took a prominent part. He was well known in the railway and engineering world as a man of large and varied experience, and of indomitable perseverance in whatever he undertook. He invented an arrangement of pipe connections between locomotive engines and tenders for water, steam, and air; and also a plan for securing and finishing the eccentrics on the crank-shafts of locomotive and other engines. He was also concerned in a method of applying sand for preventing the driving wheels of locomotives from slipping. His death took place at Spondon, near Derby, on 7th January 1893, at the age of sixty-seven. He became a Member of this Institution in 1863.

Matthew Murray Jackson was born in Leeds on 29th June 1821. He was the grandson of the famous engineer Matthew Murray (Proceedings 1882, pages 267–9), who was the owner of the Round Foundry, Leeds, and the contemporary and competitor of George

Stephenson and James Watt. His father, also an engineer and later on one of the partners in the firm, had him educated at a school in Leeds; and he was so fond of spending all his spare time at the works, that before he was ten years old he knew almost as much about machinery and the use of tools as many an apprentice who had gone through the shops. After a couple of years' study in Germany, he entered his father's business at the age of seventeen as a draughtsman, and was soon promoted to one of the managerships. The work of the then firm, Messrs. Fenton, Murray, and Jackson, comprising steam engines, machine tools, millwork, heckling and spinning machinery, afforded him an excellent training in mechanical engineering. In 1844 he was appointed chief engineer and manager to Messrs. Escher Wyss and Co., Zürich, Switzerland, who were at that time beginning to make their own machinery, instead of sending for it from Leeds; a foundry and shipbuilding yard were built, and English foremen were engaged for these departments as well as for the boiler-making and fitting shops. In a few years he had the satisfaction of seeing their first vessel, the "Republican," launched on the lake of Zürich, the first steamer ever seen in Switzerland. The difficulties to contend with were both serious and numerous. Every ton of iron had to be shipped from England or Belgium, no coal could be obtained nearer than Westphalia, and the traffic arrangements on the continental railways were at that time in their infancy. The works nevertheless prospered, and other steamers for the Swiss lakes followed in quick succession. During his twenty-four years' managership he is believed to have built over a hundred vessels for the Swiss and Italian lakes, the Rhine, Danube, and other rivers, as well as several sea-going ships for the Mediterranean and Adriatic. He was one of the first to employ high and low-pressure cylinders, on the principle of what was then known as Woolf's compound engine. Large orders of locomotives for Swiss and Italian railways, and stationary engines, millwork, hydraulic and pumping machinery, and turbines, were carried out at the same time by the firm, which for the last forty years has given regular employment to over two thousand mechanics and workmen. In 1868 he left the firm of Messrs. Escher Wyss and Co. to become engineer-in-chief of the Austrian Danube Navigation Co. at Budapest, which owns a fleet of two thousand vessels and barges, and employs over three thousand men at Budapest alone, the traffic extending from Passau on the Austrian frontier down to Varna on the Black Sea, over a waterway of about two thousand miles. During his sixteen years in the service of the company he devoted himself to the re-organisation of their fleet, overhauling two or three hundred of their steamers, fitting many with new engines and boilers, and building a large number of new vessels after his own designs, including the "Orient," the largest afloat on the Danube. For transport vessels on the Danube he adopted the plan now used also in Germany and elsewhere, of haulage by means of a wire-rope laid along the bottom of the river or canal, which was picked up by the advance of the vessel, and, after passing over a clip pulley driven by machinery, dropped back into the water at the stern. He also built the great locks, worked by hydraulic machinery, in the Danube canal. In 1884 he retired from the management, and returned to England, being at the same time appointed consulting engineer to the company, whose new vessels continued to be constructed from his designs, several being built on the Tyne under his superintendence. As recently as 1890 he returned for three months to Budapest to lend his services to the company. In 1874 he was created a knight of the Imperial Austrian Order of Francis Joseph, and in 1878 received the Cross of the Legion of Honour, in recognition of the display made by his company at the Paris Exhibition in that year. In 1882 he was a member of the Jury of the Naval and Industrial Exhibition at Trieste. His death took place at his residence at West Brighton on 4th November 1892, after a short illness, in the seventy-second year of his age. He became a Member of this Institution in 1859.

ALEXANDER LAVALLEY was born in November 1821, his father being a professor at the Academy of Medicine in Moscow, and his mother a Russian. He was educated at an English school in Tours, and entered the École Polytechnique, Paris, in 1840. Having decided to become a mechanical engineer, he spent two years in England in the works of Messrs. Bury, Curtis and Kennedy, Liverpool, and in the evenings lectured on mechanics to the foremen and workmen. Returning to France he was for a short time under M. Tétard, engineer of the Northern Railway of France; and was afterwards employed by M. Le Chatelier on different sections of the line from Paris to Lyons. In 1846 he became engineer and manager of the works of Messrs. Ernest Gouin and Co., Paris, for the construction of locomotives and machinery. In 1852 he came over to England again, for the purpose of studying the design and construction of the Menai Bridge; and on his return to France the firm of Messrs. Ernest Gouin and Co. were the first to start the building of iron bridges in France, of which they constructed a large number for that and other countries. Besides erecting a great number of bridges in Russia, the firm undertook the execution of the only tunnel on the St. Petersburg and Warsaw Railway. In 1862 they undertook the completion of the Northern Railway of Spain across the Pyrenees, a formidable work which was accomplished in two years. Owing to ill-health consequent upon incessant devotion to his duties, he then retired from the firm with a view to rest and recovery. He was next induced by M. de Lesseps to undertake the construction of the Suez Canal. The position of the work at that time was critical, owing to the Viceroy's withdrawal of the forced labour, which he had promised to furnish. In conjunction with M. Borel he succeeded by means of mechanical appliances in place of manual labour in bringing the undertaking to a successful issue, and the canal was opened for navigation on 17th November 1869, three months before the expiration of the time allowed, and without exceeding the amount of the contract. Besides excavating the canal, he also accomplished the gigantic operation of filling the Bitter Lakes with water from the Mediterranean. On the completion of the work he was appointed engineer-in-chief of the canal, his partner M. Borel having died a month before the opening. In 1878 he undertook with M. Molinos the construction of a harbour for the island of Réunion, which was completed in 1886; and also constructed a railway all round the island, in spite of the many natural difficulties that had to be overcome. His great services to his country were recognized by his being elected a Senator in 1885, after he had already been created a Chevalier of the Legion of Honour in 1853, and an Officer in 1868, and had received many other distinctions. He died on his estate at Bois-Thillard, near Pont l'Évêque in the department of Calvados, Normandy, on 20th July 1892, in the seventy-first year of his age. He became a Member of this Institution in 1881, and was also a Member of the Institution of Civil Engineers, and President in 1877 of the Institution of Civil Engineers of France, as well as a member of various other societies.

George Henry Poke was born at Plympton, Devonshire, in 1845. His father dying when he was very young, he was educated at the Greenwich school for orphans of mariners, and served his time for five years from 1860 in the factory of the Royal Dockyard, Woolwich, as an engineer student for the navy. In 1865 he resigned the service, and went to the Small-Arms Factory for about nine months, both in the drawing-office and shops. He next joined the Woolwich gas works as engineer, and from there went to the Royal Arsenal. In 1868 he received the government appointment of assistant engineer in India, in which capacity he went to Messrs. Hick, Hargreaves and Co., Bolton, on supervision work. Later in the same year he went out to India as assistant engineer in the Small-Arms Ammunition Factory, Madras. In 1870 he was transferred to the factory at Kirkee; and in 1882 was appointed chief engineer of the Government Gun-Carriage Factory, Bombay. In 1890 he returned to England on furlough for eighteen months, of which the last twelve were converted into duty in the Royal Carriage Department, Woolwich Arsenal. Whilst returning to India he died of apoplexy on board the steamer "Peshawur" in the Red Sea, on 29th September 1891, in the forty-sixth year of his age, and was buried at sea. He became a Member of this Institution in 1890.

Henry Sandham was born on 13th March 1832 at Brompton, near Chatham, being the eldest son of General Henry Sandham of the Royal Engineers. He was educated at Rugby and the

Charterhouse, and by Dr. William Bridgman of Woolwich. In 1849 he went to Russia for commercial life, but returned home in 1854, on war being declared. In 1855 he was appointed assistant to Captain Francis Fowke, R.E., for the arrangement and working of the British machinery department at the Paris Exhibition of that year. From 1856 to 1859 he had charge of machinery, partly of his own design, erected at Ipswich by Messrs. Pye Brothers for the steeping and preparation of flax, the growth of which had been introduced into Suffolk as a commercial enterprise. In 1859 he joined the Science and Art Department at South Kensington, as assistant to Captain Fowke in forming there a collection of models of architecture and building construction, with specimens of materials and of their practical application in building. In 1862 he was connected with the International Exhibition in London for the arrangement of the machinery in motion. In 1867 he went again to Paris to assist in the arrangement and erection of the British machinery in the Exhibition. In 1868 he was entrusted with the formation at South Kensington Museum of a permanent collection of models and drawings of ships, and of boilers, engines, and machinery employed in steam-ships. In 1873 he was charged with the general arrangement of the whole of the British section at the Vienna Exhibition. After thirty-three years' service with the Science and Art Department, his death took place on 13th August 1892, in the sixty-first year of his age. He became an Associate of this Institution in 1883; and in 1885 contributed a paper on the history of paddle-wheel steam navigation (Proceedings, page 121).

Institution of Mechanical Engineers.

PROCEEDINGS.

April 1893.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 20th April 1893, at Half-past Seven o'clock p.m.; Dr. William Anderson, F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following twenty-eight candidates were found to be duly elected:—

MEMBERS.

Beastow, William Henry,	Manchester.
Charlesworth, Sheard,	Oldham.
Dalrymple, Alexander,	Liverpool.
Green, William Penrose,	Leeds.
Millar, Jackson,	Singapore.
Philip, William Littlejohn,	Melksham.
Pollit, Edward Ernest,	Sowerby Bridge.
Quirk, Edward,	London.
Smith, John,	Birmingham.
Townsend, C. Collingwood, Capt. R.A.,	Fatehgarh, India.
Wallwork, Roughsedge,	Manchester.

ASSOCIATE MEMBERS.

Burden, Alfred George,	Johannesburg.
Corkhill, William,	Calcutta.
Cowell, John Ray,	London.
Lea, Arthur Henry,	Shrewsbury.
Mountain, Benjamin,	Castleford, Yorks.
Paterson, Robert Mair,	Brighton.
Segundo, Edward Carstensen de,	London.
Talbot, Frederick William,	Surbiton.

ASSOCIATES.

Clarke, Edward Fuhrmann,	Birmingham.
Darlington, John,	London.

GRADUATES.

Alderson, Charles Albert Heselton,	Lincoln.
Bruce, Robert Arthur,	Bolton.
Higgins, William Brown,	Bolton.
Monckton, Charles John,	High Wycombe.
Morgan, George Herbert,	Liverpool.
Price, William Frederick,	Preston.
Sharpley, George Ruston,	Lincoln.

The following Paper was then read and partly discussed:—

"Second Report to the Alloys Research Committee"; by Professor W. C. Roberts-Austen, C.B., F.R.S.

At a Quarter to Ten o'clock the Meeting was adjourned to the following evening. The attendance was 68 Members and 45 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Friday, 21st April 1893, at Half-past Seven o'clock p.m.; Dr. WILLIAM ANDERSON, F.R.S., President, in the chair.

The Discussion upon Professor Roberts-Austen's Second Report to the Alloys Research Committee was resumed and concluded, after the following Paper in connection therewith had also been read:—

"Tensile Tests and Chemical Analyses of Copper Plates from Fire-boxes of Locomotives on the Great Western Railway"; by Mr. WILLIAM DEAN, Member of Council, Locomotive Superintendent.

On the motion of the Chairman a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at Half-past Nine o'clock. The attendance was 62 Members and 53 Visitors.

The ANNIVERSARY DINNER of the Institution was held at The Criterion, Piccadilly, on Wednesday evening, 19th April 1893, and was largely attended by the Members and their friends. The President occupied the chair, and the Guest of the evening was the Right Honourable Lord Sandhurst, Parliamentary Secretary of the War Office. The following Guests accepted the invitations sent to them, though those marked with an asterisk * were unavoidably prevented at the last from being present. Major-General Sir Henry J. Alderson, K.C.B., R.A., President of the Ordnance Committee; Rear-Admiral H. F. Cleveland, R.N., Vice-President of the Ordnance

Committee; Rear-Admiral C. E. Domvile, Director of Ordnance, Admiralty; Captain C. C. Drury, R.N., Ordnance Committee; Colonel F. Pridham, Commissary General of Ordnance, Woolwich; Lt.-Colonel A. J. Hepper, R.E., D.S.O., Ordnance Committee; Lt.-Colonel Edmond Bainbridge, Superintendent of Laboratory, Woolwich; Lt.-Colonel D. D. T. O'Callaghan, R.A., Ordnance Committee; Lt.-Colonel C. H. Scott,* R.A., Ordnance Committee; Captain R. B. Maconochie, R.N., Ordnance Committee; Commander Joseph Honner, R.N., Assistant Secretary of Ordnance Committee; Major Arthur P. Penton, R.A., Assistant-Director of Artillery, War Office; Major C. F. Hadden, R.A., Chief Inspector of Warlike Stores, Woolwich; Major H. C. L. Holden, R.A., Proof Office, Woolwich; Captain J. H. Thomson, R.A., Central Staff, Woolwich; Mr. Ralph H. Knox, C.B., Accountant General, War Office; Mr. John Collett, Director of Contracts, Admiralty; Dr. August Dupré, Ordnance Committee; Dr. Wilhelm Kellner,* Chemist to War Department, Woolwich; Mr. Reginald H. Brade,* War Office.

Mr. Harrison Hayter, President of the Institution of Civil Engineers; Mr. T. Forster Brown,* President of the South Wales Institute of Engineers; Mr. Robert Dundas,* President of the Institution of Engineers and Shipbuilders in Scotland; Mr. Charles J. Shoppee, President of the Surveyors' Institution; Sir Frederick A. Abel, K.C.B., F.R.S., President of the Iron and Steel Institute; Mr. W. H. Preece, F.R.S., President of the Institution of Electrical Engineers; Mr. John Spear,* President of the Hull and District Institution of Engineers and Naval Architects; Mr. William H. White, C.B., F.R.S., President of the Institute of Marine Engineers; Mr. James Forrest,* Secretary of the Institution of Civil Engineers.

Mr. Robert A. McLean, Auditor; Mr. Harry Lee Millar, Treasurer.

Professor T. Hudson Beare, F.R.S.E., University College, London; Professor D. E. Hughes, F.R.S.; Professor W. C. Roberts-Austen, C.B., F.R.S., Chemist to the Royal Mint; Mr. Charles J. Wilson, F.I.C.

Charles Lowthian Bell, Esq., Mayor of Middlesbrough; Sir Joseph W. Pease,* Bart., M.P., Chairman of the Tees Conservancy;

Mr. Joseph Richardson, M.P.; Mr. Thomas Wrightson, M.P., Chairman of the Works Committee, Tees Conservancy.

The President was supported by the following Officers of the Institution:—*Past-Presidents,* Sir Lowthian Bell, Bart., F.R.S., Mr. Jeremiah Head, Mr. Joseph Tomlinson, and Mr. Percy G. B. Westmacott. *Vice-Presidents,* Professor Alexander B. W. Kennedy, F.R.S., and Mr. E. Windsor Richards. *Members of Council,* Mr. John A. F. Aspinall, Mr. Arthur Keen, Mr. Francis C. Marshall, Mr. Edward P. Martin, Mr. James Platt, Mr. T. Hurry Riches, and Mr. William H. White, C.B., F.R.S.

After the usual loyal toasts, the President proposed "The Queen's Land and Sea Forces," which was acknowledged by the Right Honourable Lord Sandhurst, Parliamentary Secretary of the War Office, and by Rear-Admiral C. E. Domvile, Director of Naval Ordnance. Mr. William H. White, C.B., F.R.S., Member of Council, proposed the toast of "The Ordnance Committee," which was acknowledged by Major-General Sir Henry J. Alderson, K.C.B., R.A., President of the Ordnance Committee, and by Rear-Admiral H. F. Cleveland, R.N., Vice-President of the Ordnance Committee. The toast of "The Civil Branches of the Services," proposed by Mr. E. Windsor Richards, Vice-President, was acknowledged by Mr. Ralph H. Knox, C.B., Accountant General, War Office, and by Mr. John Collett, Director of Naval Contracts. Professor Alexander B. W. Kennedy, F.R.S., Vice-President, proposed the toast of "Other Scientific Societies," which was acknowledged by Mr. Harrison Hayter, President of the Institution of Civil Engineers. The toast of "Our Middlesbrough Meeting," proposed by the President, was acknowledged by Charles Lowthian Bell, Esq., Mayor of Middlesbrough, and by Mr. Jeremiah Head, Past-President. The concluding toast of "The Institution of Mechanical Engineers" was proposed by the Right Honourable Lord Sandhurst, and acknowledged by the President.

SECOND REPORT TO THE ALLOYS RESEARCH COMMITTEE.

By Professor W. C. ROBERTS-AUSTEN, C.B., F.R.S.

In presenting a Second Report* to the Alloys Research Committee, it may be well to state briefly the nature of the investigation intrusted to me, and the conclusions to which the previous work had led. The main object in view was to extend a research I had previously made upon the application of the "periodic law" of Newlands and Mendeléeff to the mechanical properties of metals. This law, as originally expressed, states that "the properties of the elements are a periodic† function of their atomic weights." It had already been shown that the effect of impurities added to gold is nearly proportional to their atomic volumes, the larger the volume of the atom the greater being its effect; and the question was, does this hold good for other metals? It was manifest that the most important evidence which could be gained was that relating to the thermal disturbance which accompanies any molecular change; and, as this usually occurs at high temperatures, it was necessary to develop and perfect the methods which were available for measuring them, and for recording the results. The first Report therefore dealt with the description of certain new methods and appliances that had been adopted in conducting the inquiry, the most important being a photographic method of pyrometry. Further details respecting the pyrometric methods adopted will be found in the present Report.

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* For First Report see Proceedings 1891, page 543.

† The word "periodic" is here employed in a similar sense to that in which it is used in mathematical expressions. In the present case it signifies that, if the elements be arranged in order of their atomic weights, then their properties will be found to vary continually, and to recur after a more or less regular increase of the atomic weight. Thus, if the metals be also arranged in classes having similar properties, it will be found that the order of their atomic weights will then form a series of groups or "periods," each showing a regular progression recurring in the succeeding group.

Before proceeding however to describe the experiments that have been made, I would direct attention to some further considerations which seem to point to the possibility that the influence of small quantities of added elements on the mechanical properties of masses of a metal will be in proportion to the atomic volume of the impurity.

In the first place it must be borne in mind that the researches of Raoult,* and the conclusions of Van 't Hoff † and Arrhenius,‡ lead to the view that the molecules of small quantities of elements distributed through a mass of a solvent retain their individuality; that is, they remain free, and do not enter into combination with the mass. As regards metals, the work of Heycock and Neville,§ as well as the results of experiments described in the previous Report,‖ points to the conclusion that the added elements may retain their freedom when they are present in much larger quantities than 0·2 per cent., which is the amount of added matter usually dealt with throughout the present series of researches. No pains were spared in making this point clear. It will be evident however that the question, whether the added element does or does not remain free in the mass of the solvent, is a vital one in limiting the scope of this inquiry. If the added element enters into combination with the solvent, its individuality will be changed, and it may well be that the mechanical properties of the metallic mass will mainly depend on the degree of fusibility of the compound which is formed. If the concentration of the solution is such that a fraction of the dissolved body alone remains isolated, the influence of the volume of the added element will evidently be disturbed, as this influence is supposed to be exerted only by a single constituent of the mixture, whilst the mechanical properties of a solidified mixture are functions of both constituents. In the favourable circumstances however, where the solvent is not saturated by the added element, and where the law of atomic volumes is applicable, the work of Sorby and of Osmond has shown that a metal is seldom homogeneous, but is more often formed of rounded polyhedral grains; and the cohesion in the interior of a grain differs from the adherence between two neighbouring grains. The law of atomic volumes cannot apply to the adherence of the grains, which is regulated by other causes, such as the rate of cooling and the pressure, and whether a compound is formed which solders the grains together. It follows that, in an attempt to prove the nature of the influence of atomic volumes by mechanical tests only, anomalies and more or less grave irregularities will be met with. Experience shows that this is actually the case. If the appeal were only to mechanical tests, the position of those who think that the influence of the impurity is proportional to the volume of its atom would not be a very firm one; but there is no such limitation. The series of experiments on bodies alloyed with iron, to which reference was made in the previous report, demonstrates that, independently of all mechanical tests, the influence of impurity on the molecular transformations in iron, studied by Osmond, may be shown in several ways. These transformations may be assisted by the presence of impurity, the temperature at which they occur may be altered, or the molecular changes may even be entirely prevented by the presence of elements which behave in strict accordance with the law of atomic volumes. The thermal displacement of the critical points of molecular change—the α and β points in iron, for instance—may be produced at will; and the nature of the effect of added elements on iron may be predicted in cases which have not as yet been studied. It may be urged that the behaviour of iron is peculiar and special, but this is improbable.

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* Comptes Rendus, vol. lxxxvii. 1879, p. 167.

† Philosophical Magazine, 1888, series 5, vol. xxvi. p. 81.

‡ Philosophical Magazine, 1888, series 5, vol. xxvi. p. 99.

§ Journal of the Chemical Society, 1889, vol. lv. p. 666; 1890, vol. lvii. pp. 376 and 656; 1892, vol. lxi. p. 888.

‖ Proceedings 1891, p. 543.

It must be borne in mind that the view originally set forth, namely that "traces" of elements influence masses in proportion to the volume of their atoms, is new, and if it be true is of great importance in molecular physics. It will be well therefore to consider what evidence other observers have obtained as to the influence of the atomic volume of a *mass* of metal on its mechanical properties. Herbert Tomlinson[*] has shown that the thermal capacity of metals closely follows their atomic volume; while as regards their elasticity, he gives a table[†] showing the relation of Young's modulus to the atomic volume; and after considering the work of Wertheim,[‡] of Maxwell,[§] and of Heen,[||] he concludes on experimental evidence of his own that the value of the product of the elasticity E, when multiplied by a fractional power of the atomic volume $\frac{A}{D}$, is constant for metals, or $E\left(\frac{A}{D}\right)^{\frac{7}{3}} = 181 \times 10^4$; and that the divergences shown by several metals from this mean value arise from the fact that the presence of small amounts of impurity makes an enormous difference in the elasticity. Sutherland[¶] shows that the rigidity of metals bears a close relation to their atomic volumes; and points out that the rigidity of metals "in its essence is a kinetic phenomenon almost as simple in character as the elasticity of perfect gases." And Professor Fessenden,[**] whilst holding that the cohesion of metals is proportional to some power of their atomic volumes, seems to conclude that their rigidity varies as the fifth power of the distance between the centres of the atoms, or as (atomic volume)$^{\frac{5}{3}}$.

One other fact deserves notice. M. J. Werth has quite recently urged[††] that in the production of the diamond form of carbon, which M. Moissan[‡‡] has shown can be effected artificially, the three factors are:—(1) pressure; (2) rate of cooling; and (3) the simultaneous presence, in the metallic mass from which the diamond separates, of some body which has a smaller atomic volume than that of the carbon. M. Werth states that the effect of pressure, in enabling a body to pass from its normal form to an allotropic condition, has been indicated by me; and that the influence of the presence of a body of small atomic volume has also been indicated by me, and studied, in the case of iron, by Osmond. As regards the influence of an element of small atomic volume, he considers that, in the separation of the diamond form of carbon from iron, this condition is met by the presence of hydrogen. The influence of pressure in determining the state of a mass of a metal or alloy is still further examined in the present Report.

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[*] Proceedings of the Royal Society, vol. xxxviii. 1884–5, p. 488.

[†] Philosophical Transactions of the Royal Society, 1883, p. 32.

[‡] Annales de Chimie, 1884, vol. xii.

[§] Philosophical Transactions of the Royal Society, 1866, vol. cxxvi. part 1.

[||] Bulletins de l'Académie Royale de Belgique, 1882, vol. iv.

[¶] Philosophical Magazine, August 1891, p. 41.

[**] Chemical News, vol. lxvi. 1892, p. 206.

[††] Comptes Rendus, vol. cxvi. 1893, p. 323. (A paper sent to the Académie des Sciences, 31 Jan. 1893.)

[‡‡] Comptes Rendus, vol. cxvi. 1893, pp. 218, 458, and 460.

Molecular Porosity.—A remarkable series of experiments has recently been made by E. Warburg and F. Tegetmeier,* which would seem to demonstrate the possibility of producing eventually a degree of porosity in vitreous bodies, which will admit the passage of elements having comparatively small atomic volumes, while other elements having larger atomic volumes are strained off, thus occasioning a mechanical sifting of the elements. A receptacle, Fig. 1, was divided by a sheet of glass, which could be several millimetres thick. Sodium amalgam was placed on one side, and pure mercury on the other; the whole was then heated to a temperature of 200° C. or 400° Fahr., at which the glass becomes slightly conducting. By the aid of a Planté battery, the sodium

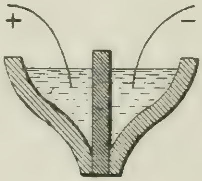

Fig. 1.

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* Wiedemann's Annalen, vol. xli. 1890, pp. 1-41. E. Warburg, Galvanische Polarization. F. Tegetmeier, Ueber die electrolytische Leitung des Glases und Bergkrystalls. Also Revue Générale des Sciences, 1892, p. 515.

atoms of the sodium silicate present were set in motion; and after the experiment had continued thirty hours it was found that a considerable quantity of sodium, amounting to 0·05 gramme or 0·77 grain, had passed into the mercury, which was originally pure. A corresponding amount of sodium had been lost by the amalgam; and the glass had exactly preserved its original weight and clearness. The glass was partly composed of neutral molecules of sodium silicate, together with free molecules both of sodium (base) and of the acid; and the free sodium was capable of being transported under the influence of the electrical current. When however Tegetmeier replaced the sodium amalgam by lithium amalgam and repeated the experiment, the sodium of the glass passed as before into the originally pure mercury, and the glass became opaque on the side touching the lithium amalgam; and after a time the opacity extended right through the thickness of the glass, and then metallic lithium began to accumulate in the previously pure mercury. It is not possible thus to chase out all the sodium present in the glass; but the free sodium atoms are replaced by those of lithium. Analysis showed that the glass originally contained 2·4 per cent. of potassium and 13·1 per cent. of sodium; but after the experiment, while retaining the same percentage of potassium, it had 4·3 per cent. of lithium and only 5·3 per cent. of sodium. The glass in which lithium has thus replaced part of the sodium is very tender, and is opaque and friable. The conclusion is that the atoms of lithium, having an atomic weight of 7 and an atomic volume of 15·98, can pass along the tracks or molecular galleries left in the glass by the sodium atoms, the atomic weight and volume of which are 23 and 16·04 respectively. When a metal of superior atomic weight and volume to sodium is substituted for the lithium—such as potassium with atomic weight 39 and atomic volume 24—it is found not possible to chase out the sodium, the new atoms being too big to pass along through the spaces where the sodium had been. We are thus confronted with a molecular porosity which can in a sense be gauged; and the mechanical influence of the volume of the atom is thus made evident.

It will be evident that there is a direct connection between the properties of a mass and the volume of its atoms. In all probability therefore the introduction of free molecules of an added element must create a disturbance, the nature and magnitude of which will bear some relation to the volume of the disturbing atoms. In the present enquiry, which is conducted essentially from the engineer's point of view, great prominence must be given to mechanical tests, upon the results of which the employment of materials depends. This fact was remembered in conducting the following experiments on the effects of certain impurities on Copper, which was one of the three metals specially selected by the Research Committee as the subject of experiment.

Influence of Impurities on Copper.—Copper is a favourable metal for study, because its industrial applications are many and varied, whilst its mechanical properties are known to be strangely affected by the addition of foreign matter. The results already obtained with iron at once suggest the question whether copper is a metal whose ultimate atoms are capable of arrangement in different ways in the molecule. Can normal copper be made to assume an allotropic state, analogous to that in which there is reason to believe iron can exist? If it can, are the properties of normal and of allotropic copper as widely different from each other as are those of the distinct varieties of certain well-known non-metallic elements? There seems to be little doubt that copper can be prepared by electrolytic deposition in an allotropic state,* in which the density of the metal is from 8·0 to 8·2, as compared with 8·92 which is that of normal copper; the allotropic variety also shows a readiness to undergo chemical change, which is not shared by ordinary copper. The evolution or absorption of heat however during gradual cooling or heating, which is evidence of marked reversible thermal effects and is a main indication of molecular change, is not so easy to detect in copper, as it is in iron which is being gradually cooled or heated. On the other hand it is held in the case of iron that subjecting the metal to any mechanical stress* which tends to produce permanent deformation of the mass enables the iron to assume an allotropic form. In this respect the purest obtainable copper seems to be singularly sensitive, inasmuch as its subjection either to stress which deforms the metal, or to annealing, the tendency of which is to reverse the effects of mechanical stress, is accompanied by profound changes in the mechanical properties. It is impossible to say, for instance, what the standard tenacity of a normal sample of pure copper should be taken to be, for so much depends on the previous history of the piece of metal, especially as regards the mechanical and thermal treatment to which it has been subjected. The following figures will show how great the variations may be. Rods of very pure electrolytic copper, all the same sample but variously treated, broke under the following stresses:—

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* Schützenberger, Comptes Rendus, vol. lxxxvi. 1878, pp. 1265 and 1397.

Treatment of Copper Rods.	Breaking Stress per sq. inch.		
	Lbs.		Tons.
Cast rods 0·2 inch diameter	18,450	=	8·237
Cast rods carefully worked and annealed . . .	40,900	=	18·259
Cast rods carefully worked at the ordinary temperature and annealed by slow cooling from a red heat . .	31,710	=	14·156
Cast rods heated to a temperature of 800° C. or 1470° Fahr. and quenched in water three times . . .	25,400	=	11·339
Cast rods worked (or forged) and not annealed . .	42,000	=	18·750

The experiments entirely confirm the results obtained in this country by Mr. Parker,† and by Professor Unwin,‡ and by M. André Le Chatelier§; but, as the latter points out, the tests by Mr. Parker and by Professor Unwin appear to have been made on unannealed copper, and the results are applicable only to the particular specimens subjected to examination. Curves plotted from the results obtained by Professor Unwin and by M. André Le Chatelier are shown in Fig. 18, Plate 31, Nos. 1 and 2. M. A. Le Chatelier has moreover called attention to the fact that the time during which the metal is annealed has a marked effect on the tenacity. A consideration of these facts shows the great difficulty of determining what should be the standard tenacity of copper; and this is well illustrated by the results obtained by the American Committee appointed many years ago to investigate the properties of the alloys of copper and tin.* Even if a standard tenacity could be fixed, it would be very difficult to obtain a sufficient quantity of copper of a standard degree of purity for the purposes of a lengthy inquiry.

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* Osmond; Carus Wilson, Philosophical Magazine, 1890, series 5, vol. xxix. p. 200; Barus, "Nature," vol. xli. 1889–90, p. 369.

† "Engineering," vol. xlvi. 3 Aug. 1888, p. 125.

‡ British Association Report, 1889, p. 746.

§ Le Génie Civil, 1891.

After many difficulties and fruitless trials, I adopted pure electrolytic copper cast in thin rods, as the material which formed the basis of the experiments; and in the preparation of these rods the following plan, suggested by Mr. Jenkins, was followed. There is usually great difficulty in making small castings of copper, owing to the rapidity with which oxidation proceeds when the liquid metal is exposed to the air, as it is when poured into a mould. Moreover, as old and well-known experiments have shown, the strength of copper is singularly affected by the presence of small quantities of dissolved cuprous oxide; and it becomes absolutely necessary, in studying the effect of single elements upon copper, to exclude the simultaneous presence of cuprous oxide. In order to ensure this, the molten metal was not brought into contact with the air at all, but the moulds formed part of the crucible in which the metal was melted.

Tubes were prepared by drilling out long rods of electric-light carbon from one end, a certain thickness of solid material being allowed to remain at the opposite end, through which a fine hole was subsequently made. The weighed amount of pure electrolytic copper was placed in a crucible sufficiently large to leave an inch of its height to spare, beneath the plug or lid into which the tubes were fixed. The arrangement is shown in the sketch, Fig. 2, in which for the sake of clearness a crucible with only a single tube is represented; but seven tubes to a single crucible were usually employed for each set of castings. The carbon tubes with their open ends downwards were placed vertically in the centre of the crucible, and packed in with fire-clay ; the whole was carefully dried, and when ready was placed in a furnace with a deep fire. When the copper was thoroughly melted, the crucible was lifted out, and then inverted, so as to cause the copper to flow into the carbon tubes. A little copper was allowed to flow out of the fine holes in the outer ends of the tubes ; and these holes were then stopped by placing the tubes upright in a bath of sand. In casting the bars containing impurity, a rich alloy of known composition was made in the first instance ; and a weighed amount of this alloy was added to the charge, which latter was well shaken when melted.

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* Report on the Alloys of Copper and Tin, 1879, p. 456.

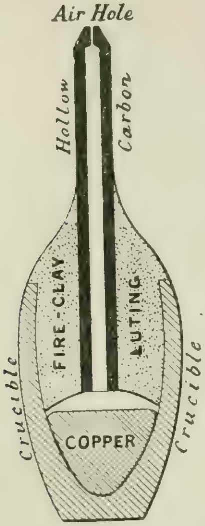

Fig. 2. One-third full size.

In the preparation of the copper rods, they were first carefully and evenly hammered, until they were somewhat flattened. They were then heated to redness for a few minutes, and plunged into cold water, and hammered until they were of square section. They were again heated to redness and quenched, and then hammered until they were octagonal. They were finally brought to an approximately circular section by passing them through grooved rolls. After a third heating and quenching, their diameter was measured by means of a micrometer, and marks were made at every half inch of their length. They were then ready for testing. If they were required to be tested at any other temperature than that of the room, a thermo-junction of platinum and platinum-rhodium wires was firmly tied down to the specimen by means of a short spiral of soft copper wire; and the whole was enclosed in a thick copper cylinder or tube of sufficient length to fill the space between the jaws of the testing machine. The ends of the tube were lightly packed with asbestos fibre, so that, whilst air currents were prevented, the tube formed a small air-bath around the specimen. The tube was very slowly heated by ordinary gas burners, until the desired temperature was reached at which the test had to be made; the gas supply was then moderated until the temperature was quite steady, and when this was the case the load was applied. The test pieces were loaded at such a rate that fracture occurred in about fifteen minutes from the first application of load.

This copper was analysed by one of my own students, Mr. Allan Gibb, who has devoted much care and attention to this particular portion of the investigation. It was found to be singularly pure, containing 99·99 per cent. of copper. Neither lead, silver, antimony, arsenic, tin, iron, nickel, sulphur, nor phosphorus could be detected, though they were carefully sought for. On the other hand a minute trace of bismuth was detected. The method of analysis adopted is given in the appendix, page 138.

The electrical conductivity of this metal after annealing was very high; tested by Mr. William Gowland, a well-known authority upon the subject, it proved to be 102, pure copper being usually 100 or 101.

Testing Machine.—A small hydraulic machine of the single-lever type was employed, the general arrangement of which is shown in Figs. 6 and 7, Plate 27. The load is applied by a hydraulic ram R, and measured by weights W carried at the end of a bell-crank lever B working upon steel knife-edges. The maximum tension that could be exerted on the specimen S was two tons, and the leverage was twelve times. The little appliance employed for determining the limit of elasticity is shown in Figs. 8 and 9; it consists of a frame F carrying a multiplying lever L, to the outer extremity of which is attached a second lever carrying a mirror M. A ray of light is allowed to fall upon this in a direction parallel to the axis of the machine, and is reflected upon a scale 50 inches distant. The frame F is supported upon three hardened steel screws, two of which are sharpened and rest in slight centres punched in the test rod S, being held in them by spring clips. One of these two screws however is connected to the frame by means of the multiplying lever L; and hence any elongation of the rod is greatly multiplied by the mirror M. The elongation is by this means magnified to the extent of 2,000 times. The total length of each specimen S was about seven inches, and the length between the jaws was four inches.

The calculations for the strength of the rods were made both upon the original and upon the final areas which the rods assumed before fracture; but the final section was not in all cases easy to determine. The rods usually fractured in one of two ways. Either the rod broke suddenly, when the case presented no difficulty; or sometimes the metal did not break until it had become drawn out to a fine knife-like edge. In the latter cases the beam of the machine dropped rapidly; and in some trials it was found that, by carefully measuring the place of stricture, and then applying again a diminished load, further extension did not occur until the load per unit of area of the constriction equalled the maximum load that had been previously applied to the rod; and that, when this load was exceeded, a further rapid constriction would occur. On account of this fact, in all cases where such rapid flow occurred, the area taken for calculation was that of the rod immediately prior to the constriction taking place. The tenacity of the worked and annealed electrotype copper, which forms the basis of the experiments, is given in curve No. 3, Fig. 18, Plate 31. The metal, as already stated, proved to be singularly pure.

In view of the great difficulty of obtaining large quantities of pure copper, it is not easy to see what better method could have been adopted. Nevertheless such irregularities as are shown by the respective curves plotted in Fig. 18, Plate 31, are probably due, less to

(*continued on page* 119.)

TABLE 1.—(*continued to page* 118).

Tensile Tests of pure and variously alloyed Copper Rods subjected to various mechanical treatment.

No. of Test.	Temperature of Rod.	Original Diameter.	Area of Cross Section.		Coefficient of Contraction.	Total Load applied.	Tensile Strength per square inch		Percentage of Elongation.	Description of Rods. *See curves plotted in Plate* 31.
			Original.	Final.			on Original area.	on Final area.		
No.	C. F.	Inch.	Sq. Inch.	Sq. Inch.	Coeff.	Lbs.	Lbs.	Lbs.	Per cent.	
1	20° = 68°	0·234	0·0430	0·0353	0·82	1068	24,840	30,250	20·0	*Curve* 6. Copper containing 1·2 per cent. Arsenic. Rods tested as cast, without preliminary working. Fractures like those in set containing 1·5 per cent. Arsenic (tests 39–44).
2	130° = 266°	0·221	0·0384	0·0330	0·86	786	20,470	23,820	16·6	
3	224° = 435°	0·226	0·0401	0·0302	0·75	660	16,460	21,850	15·0	
4	266° = 511°	0·240	0·0452	0·0415	0·92	648	14,340	15,620	4·0	
5	346° = 655°	0·229	0·0412	0·0327	0·79	612	14,860	18,720	10·0	
6	15° = 59°	0·218	0·0373	0·0333	0·89	672	18,020	20,180	20·0	*Curve* 8. Very pure Copper with 0·1 per cent. Bismuth added. Rods tested as cast. All exhibited a columnar structure, in some cases developing very striking planes of fracture.
7	101° = 214°	0·193	0·0292	0·0265	0·91	336	11,510	12,680	15·0	
8	162° = 324°	0·195	0·0299	0·0299	1·00	168	5,620	5,620	0·0	
9	199° = 390°	0·218	0·0373	0·0373	1·00	144	3,860	3,860	0·0	
10	274° = 525°	0·208	0·0340	0·0333	0·98	168	4,940	5,050	0·0	
11	292° = 558°	0·223	0·0390	0·0387	0·99	108	2,770	2,790	0·5	

No.	C. F.	Inch.	Sq. Inch.	Sq. Inch.	Coeff.	Lbs.	Lbs.	Lbs.	Per cent.	
	Effect of working upon rods of pure Copper, cast side by side.									
12	18°=64°	—	—	0·0206	—	1104	—	53,600	12·0	Worked. Fracture red, fibrous.
13	Do.	0·269	0·0568	0·0415	0·73	684	12,040	16,480	5·0	Not worked. Fracture short crystalline.
	Effect of slow and of rapid cooling upon rods of pure Copper, cast side by side.									
14	18°=64°	0·246	0·0475	0·0380	0·80	876	18,450	23,050	20·0	Not worked.
15	Do.	0·248	0·0483	0·0291	0·60	1188	24,600	40,840	7·0	Hammered, heated, and quenched.
16	Do.	0·270	0·0572	0·0410	0·72	1814	31,720	44,250	21 to 33	Hammered, heated, and slowly cooled.
	Effect of slow and of rapid cooling upon rods containing 0·2 per cent. Arsenic, cast side by side.									
17	18°=64°	0·241	0·0456	0·0299	0·65	984	21,580	32,910	30 to 40	Not worked.
18	Do.	0·225	0·0398	0·0289	0·73	1200	30,150	41,530	30·0	Hammered, heated, and quenched.
19	Do.	0·218	0·0373	0·0266	0·71	1140	30,570	42,850	20·0	Hammered, heated, and slowly cooled.
	Effect of heating and quenching alone, without other work, upon rods of pure Copper, cast side by side.									
20	18°=64°	0·241	0·0456	0·0389	0·85	900	19,740	23,130	35·0	Tested as cast.
21	Do.	0·238	0·0445	0·0235	0·53	914	20,540	38,900	21 to 42	Tested after having been heated and quenched three times in succession.

TABLE 1.—(*continued from preceding page*).

Tensile Tests of pure and variously alloyed Copper Rods subjected to various mechanical treatment.

No. of Test.	Temperature of Rod.	Original Diameter.	Area of Cross Section.		Coefficient of Contraction.	Total Load applied.	Tensile Strength per square inch		Percentage of Elongation.	Description of Rods. *See curves plotted in Plate* 31.
			Original.	Final.			on Original area.	on Final area.		
No.	C. F.	Inch.	Sq. Inch.	Sq. Inch.	Coeff.	Lbs.	Lbs.	Lbs.	Per cent.	
22	11° = 52°	0·210	0·0346	0·0211	0·61	1044	30,170	49,480	37·0*	*Curve* 3. This set of rods was made from copper of a high degree of purity. They were hammered, rolled, and slowly annealed. All gave fibrous fractures, passing into granular as the temperature of the test increased. * Limit of elasticity 2,600 lbs. per square inch.
23	15° = 59°	0·197	0·0304	0·0130	0·43	900	29,600	69,300	27·0	
24	100° = 212°	0·205	0 0330	0·0283	0·86	1020	30,920	36,010	30·0	
25	102° = 216°	0·210	0·0346	0·0204	0·59	984	28,150	48,210	30·0	
26	151° = 304°	0·209	0·0343	0·0235	0·68	1032	30,090	43,930	23·0	
27	218° = 424°	0·187	0 0275	0·0133	0·48	798	29,020	60,000	25·0	
28	249° = 480°	0·208	0·0310	0·0198	0·58	960	28,240	48,490	37·0	
29	325° = 617°	0·188	0·0277	0·0149	0·54	702	25,340	47,130	21·0	
30	370° = 698°	0.195	0·0299	0·0165	0·55	630	21,070	38,180	20 0	
31	401° = 754°	0·190	0·0283	0·0198	0·70	594	20,990	30,000	15·0	
32	470° = 878°	0·180	0·0254	0·0238	0·94	552	21,730	23,190	—	

No.	C. F.	Inch.	Sq. Inch.	Sq. Inch.	Coeff.	Lbs.	Lbs.	Lbs.	Per cent.	
33	18° = 64°	0·225	0·0398	0·0289	0·72	1200	30,150	41,520	30·0	*Curve* 4. Copper containing 0·2 per cent. Arsenic. Rods cast as described on page 111, and carefully worked and annealed like Nos. 22–32.
34	101° = 214°	0·210	0·0346	0·0201	0·58	1068	30,880	53,140	30·0	
35	144° = 291°	0·200	0·0314	0·0218	0·69	972	30,960	44,590	21·0	
36	249° = 480°	0·205	0·0330	0·0188	0·57	948	28,730	50,430	30·0	
37	18° = 64°	0·216	0·0475	0·0380	0·81	876	18,450	23,050	20·0	Rods of very pure Copper, tested as cast, without preliminary working.
38	Do.	0·241	0·0456	0·0389	0·85	900	19,740	23,140	35·0	
39	15° = 59°	0·239	0·0449	0·0314	0·70	1188	26,460	37,830	20·0*	*Curve* 7. Copper containing 1·5 per cent. Arsenic. Rods tested as cast, without preliminary working. Fractures finely drawn at low temperatures, and coarsely granular at high ones; and paler in colour than those of pure copper. * Limit of clasticity 4,260 lbs. per sq. in.
40	18° = 64°	0·225	0·0397	0·0295	0·74	1008	25,400	34,170	25 to 50	
41	116° = 241°	0·212	0·0353	0·0283	—	828	23,460	29,260	26·0	
42	215° = 419°	0·230	0·0415	0·0299	0·72	807	19,450	27,000	37·0	
43	260° = 500°	0·230	0·0415	0·0214	0·51	762	18,360	35,610	irregular	
44	308° = 586°	0·230	0·0415	0·0415	1·00	624	15,030	15,040	0·0	
45	15° = 59°	0·212	0·0353	0·0283	0·80	762	21,530	26,930	13·6†	Copper containing 0·2 per cent. Tellurium. † Limit of elasticity 1,193 lbs. per square inch.
46	Do.	0·215	0·0363	0·0211	0·58	840	23,140	39,820	considerable	
47	Do.	0·250	0·0491	0·0430	0·87	840	17,110	19,540	13·0	Copper containing less than 0·05 per cent. Potassium, tested as cast.
48	Do.	0·225	0·0398	0·0308	0·77	916	23,020	29,740	11·0	Copper containing less than 0·05 per cent. Potassium, rolled and annealed.

TABLE 1.—(*concluded from page* 114).

Tensile Tests of pure and variously alloyed Copper Rods subjected to various mechanical treatment.

No. of Test.	Temperature of Rod.	Original Diameter.	Area of Cross Section.		Coefficient of Contraction.	Total Load applied.	Tensile Strength per square inch		Percentage of Elongation.	Description of Rods. *See curves plotted in Plate* 31.
			Original.	Final.			on Original area.	on Final area.		
No.	C. F.	Inch.	Sq. Inch.	Sq. Inch.	Coeff.	Lbs.	Lbs.	Lbs.	Per cent.	
49	18° = 64°	0·217	0·0370	0·0165	0·45	1236	33,420	74,900	37·0*	
50	100° = 212°	0·205	0·0330	—	—	1020	30,920	—	30·0	*Curve* 5.
51	170° = 338°	0·211	0·0350	0·0170	0·48	1020	29,150	60,000	35·0	Rods of very pure Copper contaminated with 0·5 per cent. Arsenic. These were all cast in one set, and very carefully worked and annealed.
52	170° = 338°	0·215	0·0363	0·0139	0·38	1178	32,470	84,740	30·0	
53	258° = 496°	0·213	0·0356	0·0154	0·43	1068	30,030	69,350	23·0	* Limit of elasticity 3,240 lbs. per square inch, confirmed by a second test.
54	340° = 644°	0·206	0·0333	—	—	900	27,030	—	—	
55	446° = 835°	0·205	0·0330	0·0277	0·84	660	20,000	23,820	13·0	

(*continued from page* 113.)

variations in the duration of the test, than to want of uniformity either in the amount of work done upon the samples tested, or in the annealing to which the test pieces were subjected. This is shown by the fact that the coefficients of contraction, found by dividing the area of the fractured surface of the test piece by its initial area, while they vary, as do those given by André Le Chatelier, from 0·43 to 0·94, do not show the same uniform and progressive rise with the temperature of the experiment (see tests 22 to 32 in page 116). The metal appears to be quite as ductile at the ordinary temperature as the samples tested by M. Le Chatelier; which tends to show that the annealing to which they had been subjected had been as complete as in his samples. The copper as cast, when tested at the ordinary temperature of 18° C. or 64° F., showed a tenacity of 18,450 lbs. or 8·237 tons per square inch (test 14). Copper employed for industrial purposes is worked and annealed; and, as already stated (page 109), this might raise the tenacity to 41,000 lbs. or 18·3 tons per square inch, and upwards, and no amount of annealing would reduce the tenacity to that of the cast metal. The results of the tests are given in Table 1, pages 114–118, and in Fig. 18, Plate 31.

Arsenic, Antimony, and Bismuth.—First as regards the effects of the presence of arsenic. The effect of arsenic on copper is shown by the curves Nos. 4, 5, 6, 7, in Fig. 18. Nos. 6 and 7 were not worked; if they had been, they would probably have come much higher. A series of four rods was carefully prepared of pure copper alloyed with 0·2 per cent. of arsenic, and the results obtained from the tests (Nos. 33–36) are given in Table 1, and are plotted in the curve No. 4 in Fig. 18. The tenacity of pure copper at 300° C. or 570° Fahr. is 9·38 tons per square inch (curve 2), with an elongation of 34·6 per cent. (A. Le Chatelier); while that of the arsenical copper, according to the results of the experiments now published (curve 5), is 28,230 lbs. or 12·6 tons per square inch at that temperature. It appears safe to conclude that the superior strength and ductility of arsenical copper are maintained at the temperatures attained by the plates of the fire-boxes of locomotives; and it is harder than pure copper. This would explain the preference of the makers of locomotive fire-boxes for old brands of copper, supplied before the elimination of arsenic was so fully understood by smelters. This is borne out by some experiments recently made by Professor Hampe,* who has studied the effects of arsenic, antimony, and silicon, on pure copper. He employs very pure copper in the form of wire, having an initial tenacity of 49,120 lbs. or 21·03 tons per square inch; and shows that the effect of the presence of 0·351 per cent. of arsenic is to raise its strength to 72,380 lbs. or 32·26 tons; while with a larger proportion, 0·808 per cent. of arsenic, the strength is somewhat less, namely 69,380 lbs. or 29·7 tons. The influence of antimony appears to be even more marked, the strength of copper with 0·26 and 0·529 per cent. being respectively 73,800 lbs. or 32·96 tons, and 77,900 lbs. or 34·77 tons. No attempt was made to ascertain the strength of these alloys at temperatures higher than that of the atmosphere.

A curious form of fracture was presented by the rods containing bismuth. All exhibited a more or less quasi-fibrous fracture, and rather suggested that of a network of cells; but in a few cases a very fine surface as of cleavage planes was the result, an example of which is shown in Fig. 3.

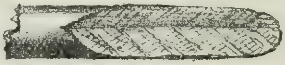

Fig. 3. Full size.

Questions of great interest are raised by the curves shown in Fig. 18, Plate 31, which represent the influence of arsenic and bismuth on the tenacity of copper. The results of Professor Hampe's experiments just referred to would seem to show that antimony behaves like arsenic, and when present in small quantity greatly strengthens the copper. Bismuth on the other hand, as the experiments submitted to the Committee show, renders copper singularly weak; and the peculiar behaviour of bismuth pointed to the necessity for a very close examination of its mode of action. For instance, curve No. 8, Fig. 18, represents copper containing

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* Chemiker Zeitung, 25 May 1892, p. 726.

0·1 per cent. of bismuth. It was too brittle to work, and has at the ordinary temperature a tenacity of 18,000 lbs. or about 8 tons per square inch; and when the members of the series are tested at graduated rising temperatures the fall in tenacity is very rapid, and there is practically no elongation. The effect of bismuth however does not appear to be quite proportional to the amount present, as copper with 0·2 per cent. has a tenacity of only 7,000 lbs. or about 2 tons per square inch. The prejudicial effects of bismuth it would appear do not vanish, even though but a trace be present. For instance, curve No. 3 is from singularly pure copper, but analysis showed it still to contain 0·002 per cent. of bismuth. It worked well, and the entire series is strong, but the elongation is small, as shown by test No. 13 in Table 1 (page 115).

Why bismuth, when present in amounts above 0·1 per cent., should differ so widely in its action from arsenic and antimony is not at first apparent. According to the classification of Mendeléeff, arsenic, antimony, and bismuth all belong to the same family, of which nitrogen is the type. It is true that the atomic volume of bismuth 20·9 is higher than that of arsenic 13·2, or of antimony 17·9; and therefore, according to the principle I have laid down, it ought to diminish the tenacity of copper, of which the atomic volume is only 7·1; but then the influence of arsenic and antimony should be exerted in the same direction as bismuth, though in a less degree. It soon became evident that a complex and tedious series of experiments could alone afford hope that the peculiar action of bismuth would be explained; and it was clear that the method detailed in the previous report was the one to follow in the attempt to determine what happens during the solidification of copper containing bismuth. A comprehensive series of alloys was prepared, and each member of the series was analysed in the metallurgical laboratory of the Royal College of Science; and the results will be given subsequently. Each alloy was melted, and the thermopile, protected by a very thin tube of fire-clay, was inserted in the molten mass, and its behaviour during cooling was studied by the aid of the autographic method of registration. The results of these experiments, which have extended over nearly a year, are shown in Fig. 19, Plate 32, and reveal a wholly unexpected fact in connection with the action of bismuth on copper. On the left of the diagram will be found the time-temperature curve, No. 1, of the cooling of the purest copper which could be procured; this and the rest of the curves shown in Fig. 19 are facsimiles of the photographs actually obtained. It will be observed that the portion of the curve No. 1 which represents the evolution of the latent heat of fusion is closely horizontal, and the angles are comparatively sharp. In general this is an indication of the purity of the metal under examination. An incidental point of interest deserves mention : there is a slight depression at the extreme left, which shows that *surfusion* took place, the copper having passed below the freezing point before it actually became solid. The rest of the curves show the gradual fall in the solidifying point of the copper, produced by the addition of increasing amounts of bismuth. The curves numbered 2 to 10 on the diagram have also the temperatures as ordinates and the times as abscissæ ; but each curve has been arranged diagrammatically at such a distance from its neighbour that the abscissa of its higher initial point of solidification represents the percentage of bismuth it contains. Consequently the dotted mean curve drawn between these higher solidifying points will represent the curve of temperature of solidification of the entire series.

It will be observed that each curve representing the cooling of a copper-bismuth alloy has a second or lower point of solidification upon it, and that this lower point occurs at a constant temperature in each, very close to the melting point of bismuth itself ; consequently a line drawn through these lower points is approximately horizontal. The existence of a second point of solidification is evident even when the copper contains only one per cent. of bismuth ; and this fact goes far to explain the peculiar action of bismuth upon copper. It would appear that, however poor or however rich in bismuth the alloy with copper may be, a portion of bismuth, containing perhaps a little copper, always remains fluid until the temperature of the mass has fallen to 268° C. or 514° F., the point at which bismuth itself solidifies. The presence of a fluid constituent in an alloy, long after the mass itself has become solid, is doubtless the determining cause which enables the metal to assume a highly crystalline and consequently an intensely brittle structure. So far as I know, the cause of the peculiar behaviour of bismuth could not have been revealed by any other method of investigation than the one adopted, which is a direct outcome of the work of the Committee, and of which an account was published for the first time in the previous report.

Judging from their polished surfaces, the alloys of copper rich in bismuth are to all appearance as coherent as the alloys of copper and tin, which possess great strength and have such wide industrial application, as "gun-metal" and "bell-metal" for instance. Bell-metal contains 75 per cent. copper and 25 per cent. tin; replace the tin by bismuth, and an apparently coherent alloy is produced. It is not sonorous however, and has but little tensile strength; and the persistence with which a portion of the alloy remained fluid while the mass was cooling doubtless explains this weakness. On solidification nearly all the series of alloys reject a small portion of a very fluid alloy, which is squeezed to the surface, and may often be detached as a little button. This fact explains a certain want of regularity in the curves, Nos. 3 and 6 for instance, Fig. 19, Plate 32, as the analyses of the alloys were made after the cooling curves had been taken, and some portion of this rejected part of the alloy may, in a few instances, have been lost; and a small source of error has thus been introduced, which was not recognised until the work was far advanced. Analysis proved that these detachable buttons consist of bismuth containing 0·10 per cent. of copper: a fact which is entirely in accordance with the recent observation of Heycock and Neville,* who have shown that bismuth is soon saturated with copper, as little as 0·4 per cent. of copper being sufficient to effect this, while as much as 1·0 per cent. of other added metals is required to effect the molecular saturation of copper.

Before leaving the consideration of the effects of impurities, so far as they have as yet been examined, it may be well to refer to the analysis of a sample of copper given in the appendix, page 138.

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* Journal of the Chemical Society, 1892, vol. lxi. p. 888.

The metal was taken from a locomotive fire-box which possessed singular endurance. The engine had been running on the Metropolitan Railway for twenty years and a half, and had covered 500,000 miles. The specimen was supplied to the Research Committee by Mr. J. J. Hanbury at the request of Mr. Tomlinson, Past-President. Analysis proves it to be very impure, notwithstanding the fact that in specifications for the metal of which fire-boxes are constructed it is usual to direct that it shall not contain more than 0·5 per cent. of impurity. This sample contains as much as 1·3 per cent. of impurities, of which 0·4 is lead, 0·37 arsenic, and 0·3 nickel. At present no satisfactory explanation can be given of the singular qualities of this sample of copper; but the work of André Le Chatelier* has shown that at 400° C. or 750° F., a temperature which may be attained in fire-boxes of locomotives, pure copper is singularly liable to disruption. Its very ductility is a source of danger, for even the deformation produced by successive expansions and contractions will destroy it. The presence of small quantities of foreign elements, such as aluminium or nickel, increases the endurance of the metal by rendering it less ductile. The case in point is a remarkable one, and serves to show how very complicated the question becomes when various impurities act on a metallic mass in presence of one another.

Influence of Impurities on Annealing.—Experiments are in progress with a view to ascertain in what order impurities prevent copper from recovering its original strength and ductility on annealing, after it has been strained beyond the limit of elasticity. The question however is a difficult one; for, as Professor T. Hudson Beare found in the course of some careful experiments on copper, there was always a large permanent set after the first application of the load.†

Effect of Pressure.—The passage of iron from one allotropic modification to another is accompanied not only by a change of heat capacity but also by a change of volume. When a mass of iron cools down from a temperature of 1,000° C. or 1,800° F., it also contracts, until at the point of recalescence it suddenly expands; after which it again contracts, as it cools to atmospheric temperature. An experiment described in the previous Report (Proceedings 1891, page 565) indicated the probability that pressure lowers the critical points of iron and steel. Osmond* specially refers to this experiment, which he says is the first and only one as yet made that appears to indicate the influence of pressure on the position of the critical points. The effect of pressure he suggests is analogous to that established by MM. Mallard and H. Le Chatelier,† who showed that pressure lowers the point of transformation of iodide of silver from 146° C. or 295° F. to the ordinary temperature of 15° C. or 60° F.

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* Le Génie Civil, 1891.

† "Industries," 1891, vol. xi. p. 529.

By compressing a piece of steel in a hydraulic press, it should be possible to obtain recalescence at a lower temperature than would be the case if the pressure were not applied. Observations were made by the eye in order to see whether such a lowering of the recalescence point could be detected in a piece of compressed steel; but it was found that lateral flow of the test piece rendered the experiment difficult, by preventing the application of a sufficient stress until after the metal had passed through its allotropic change, and had become more or less rigid. Moreover the orifice in which the thermo-junction was placed in the specimen became obliterated by the lateral flow of the metal. One such experiment however is given. A cylindrical piece of steel 1 inch long and $\frac{3}{4}$ inch diameter was bored through two-thirds of its length with an axial hole 1-10th of an inch diameter. A thermo-junction was carefully prepared by wrapping long fibres of asbestos round the two wires forming it, so as to insulate them from each other; and the junction so prepared was allowed to protrude from the face of one of the two dies by which the pressure was applied, so as to enter the hole in the block of steel. It is obviously necessary to insert the junction in a hole whose axis is parallel to the direction in which the pressure is applied; otherwise the deformation which takes place would compress the thermo-junction. The mass was heated to 1,000° C. or 1,800° F.; and it was found that without the application of pressure the recalescence occurred at 650° C. or 1,200° F.; and that when a total load was applied of 4 tons, equivalent to 9 tons per square inch, recalescence occurred at 620° C. or 1,150° F., and was comparatively feeble.

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* Rapport sur les Essais de Trempe. Commission des méthodes d'essais des matériaux de construction, section A.

† Comptes Rendus, vol. xcix. 1884, p. 157.

This experiment proved to be difficult to repeat; and a closed or recessed die was therefore made of steel, in which pressure could be applied all round the test piece in a way that was not possible in the previous experiment. The die consisted of a heavy steel collar of 2½ inches external and 5–8ths inch internal diameter. One end was closed by a short hardened plug of steel, and the opposite end was provided with another and longer plug, through which an axial hole had been made for the insertion of the thermo-junction. The specimen was heated in connection with a separate thermo-pile, until the required temperature of 1,000° C. or 1,800° F. was attained; it was then transferred to the die, and pressure was quickly applied. A marked lowering of the recalescence point was observed; but the experiment was open to objection that, on account of the more intimate contact between the die and the steel specimen when the latter was put under pressure, the rate of cooling was greatly

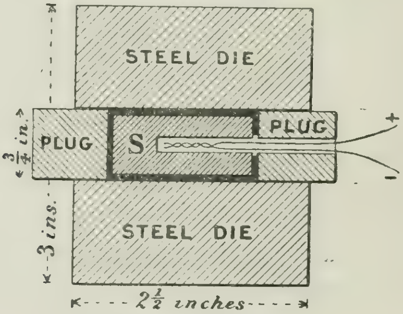

Fig. 4. Half size.

increased. A larger die was therefore prepared, of which a dimensioned sketch is given, Fig. 4; and each block of steel S was carefully wrapped in an asbestos covering before it was heated, thus ensuring a hot, sound, non-conducting coating to the specimen at the commencement of the experiment. At the same time an autographic record was taken of the temperature. The thermo-junction was not calibrated; but pairs of autographs were taken, one without any pressure being applied to the specimen and with the normal rate of cooling, and then one with the die under pressure. A single block of steel was also employed in order to obtain a set of four curves, by which to show the effect of water-hardening and of oil-hardening. Three sets of experiments in all were made, and four typical curves are given, Fig. 20, Plate 33. From a study of these it will be evident that there calescence point is lowered by pressure; but it was found that this lowering is not effected unless the load is applied at a temperature well above that at which recalescence takes place.

Bismuth, Lead, Tin.—It has long been known* that when a triple alloy of bismuth, lead, and tin, which bears Newton's name, is cooled down from the molten state, there occurs, long after the metallic mass has solidified, a remarkable rise in its temperature. Experiments made in view of the present Report show that this evolution of heat occurs generally at 46° C. or 115° F. An evolution of heat also takes place if the solid mass is cooled rapidly by quenching in water. This effect however disappears after the third or fourth heating; but may be restored by remelting the mass, or by raising it to a temperature just below its melting point. A suitable alloy for the experiment is the one containing 50 per cent. bismuth, $31\frac{1}{4}$ per cent. lead, and $18\frac{3}{4}$ per cent. tin. The appearance of the fractured surface of the mass, if broken before the evolution of heat, is plate-like, crystalline, and almost vitreous; but after the thermal change the fracture is grey, dull, and finely grained. It will be evident that the changes this alloy undergoes present certain analogies to those which take place in steel during the hardening by rapid cooling from a high temperature, and when the metal cools slowly from bright redness. In the latter case, if low-carbon steel be the subject of the experiment, there are, as has already been pointed out in the previous Report, at least two distinct evolutions of heat: one at 855° C. or 1,571° F., due it is believed to a molecular change in the iron; and the other at 655° C. or 1,211° F., arising from a change in the relation between the carbon and the iron. The alloy now under consideration contains three constituents; and the change which is made evident by evolution of heat must clearly be due either to a change in the mutual relations of the constituent metals, or else to polymerization or redistribution of the atoms in the molecules of the solid mass, either of which changes is attended with the evolution of heat. That molecular modification does take place in these alloys during cooling has been shown by E. Wiedemann* and by Spring.† In steel, carbon is present, and complicates the problem under examination, which is not the case with the triple alloy; but in the latter it is possible that one of its constituent metals may play a part analogous to that of carbon.

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* Ditte, Leçons sur les Métaux, 1891, part i. p. 21.

A careful study was therefore made of the behaviour of the alloy, and it may be well to publish the results in full at some future time; at present it is only necessary to summarise the conclusions to which the investigation appears to lead. The question arises, is the quenched Newton's metal the analogue of hardened steel? First, as regards change of volume, Ermann and afterwards Kopp found that the expansion of similar alloys is abnormal. The present experiments show that the change from the vitreous variety of the alloy to the finely crystalline is accompanied by an expansion of about 0·8 per cent. Steel also expands during the operation of hardening. The tenacity of the alloy in the vitreous state is very low, only about 1 ton per square inch; but after the molecular change a maximum of 2¼ tons per square inch is attained, the effect being the same whether the change has taken place spontaneously, or has been induced by rapidly cooling the alloy.

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* Wiedemann's Annalen, vol. iii. 1878, p. 237.

† Bulletins de l'Académie Royale de Belgique, vol. ii. 1886.

Annealing the bars at a temperature of 80° to 90° C., or 176° to 194° F., after the molecular change has taken place, appears slightly to increase their strength. The alloy solidifies at or about the temperature of 96° C. or 205° F., with a range of pastiness extending over several degrees, which prevents any mechanical measurements from being made until the mass has cooled to about 92° C. or 198° F. Throughout the range of temperature between 92° and 80° C., or 198° and 176° F., it contracts at an average rate of 0·000144 of its length per degree centigrade or 0·000080 per degree Fahrenheit; and the contraction continues, but in gradually decreasing amount, until at 49° C. or 120° F. it ceases, and the metal commences to expand. The amount of the expansion is considerable, over one per cent. of its linear dimensions; and appears to be due to some process resembling that of combination, for it requires an appreciable amount of time for its complete development, and is accompanied by a considerable evolution of heat. If on the other hand the alloy be cooled too slowly, the evolution of heat is not well marked. The converse phenomena of contraction with absorption of heat, noticed upon reheating the alloy, does not occur at the expected temperature, but at a higher; and the fact that the change is thus not truly reversible supports the view that the molecular change in the alloy is due, as is doubtless the case in steel, to combination and dissociation occurring in the solid mass.

Under these circumstances it became interesting to see whether the application of pressure would cause the change to take place at a lower temperature than that at which it would occur without pressure. A steel die was formed with a surrounding water-jacket, Fig. 5. The plug of the die had a steel socket, in which the thermo-junction was inserted, so that the pressure did not come upon it in any way. This was found to be necessary, as otherwise the insulation failed, and the metal was "squirted" along the wires, causing a short circuit. The alloy N was poured into the cavity of the die, which had previously been lined with several folds of paper; the die was closed and placed in the press, and then heated until the metal again became fluid. A steady stream of cold water was then run through the water-jacket, and by the aid of a thermo-junction, inserted in the socket before mentioned, an autographic record of the temperature was taken, whilst pressure was steadily applied to the die. It had previously been found that

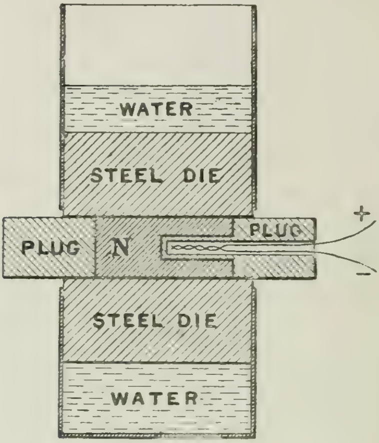

Fig. 5. Half size.

the abnormal rise in temperature in the absence of pressure was coincident with the expansion of mass. The result of the experiment showed that under a pressure of 1 ton per square inch the temperature at which the thermal change took place was lowered as much as 4° C. or 7° F., and that a pressure of about 4 tons per square inch was sufficient to obliterate the thermal disturbance altogether. It is interesting thus to see that, where the pressure is sufficient to cause the particles of the mass to assume the quasi-fluid state, the changes are so greatly modified, Fig. 21, Plate 34. Of the five typical curves here given, No. 1 represents the normal cooling of the alloy in air; No. 2 when a thin glass tube was used as an envelope; No. 3 when the alloy was poured into the die and the two plugs closed up against it, but without the direct application of pressure by the press, the only pressure therefore being that resulting from the resistance of the walls of the die and from friction of the plugs; Nos. 4 and 5 when a pressure was applied of 3 tons and 18 tons per square inch respectively. In No. 3 the pressure is uncertain in amount, because not only would the plugs yield a little to the expanding metal, but lateral flow of the metal may have taken place.

The effect of pressure in lowering the critical point in this alloy is evident; and it was interesting to ascertain whether the compression of the mass had really prevented the alloy from undergoing the molecular change from the vitreous to the grey variety; or whether the recalescence had been so gradual that there was no sudden augmentation of temperature in the cooling mass, such as would be indicated by a marked discontinuity in the autographic curve. The die was accordingly made in halves, so that it could be rapidly opened when the pressure was released. The solid cylinder of compressed alloy was removed and fractured with as little delay as possible; but it was found that the change, though not complete, was far advanced. It is impossible to say whether the change occurs directly the pressure is removed, or during the time it has been applied.

Chromium Steel.—The question of the shifting of the temperature at which the molecular changes in iron and steel take place is one of much importance. Osmond has already shown that, if the initial temperature to which a mass of carbon steel is raised be a high one, the critical points may occur at temperatures which are many degrees lower than those at which they occur when the steel is heated to the usual initial temperature of about 900° C. or 1650° F. adopted in these experiments. Very interesting results were obtained with some specimens of chromium steel supplied by Mr. Hadfield, of which the cooling curves are shown in Fig. 22, Plate 35. The sample most used was one containing the following percentages:—chromium 15·12, carbon 1·79, silicon 0·61, sulphur 0·08, phosphorus 0·04, manganese 0·28 per cent.; and the first autographic curve obtained from it failed to show any but the slightest indication of molecular change, which occurred at the elevated temperature of 840° C. or 1534° F., the piece of metal having been heated to 1270° C. or 2318° F., and slowly cooled. The experiment was repeated, curve No. 4, the heating being continued to the still higher temperature of 1295° C. or 2363° F., with the result that no molecular change at all could be detected. It was ultimately found that the recalescence occurred only when the metal had been moderately heated, or else when it was cooling down from the fused state; and that heating the cold metal up to an intermediate temperature of 1300° C. or 2370° F. caused the evidence of molecular change to disappear when the mass cooled. When the temperature of initial heating was 950° C. or 1740° F. (curve No. 3), instead of being 1280° C. or 2340° F., it was found that the temperature of true recalescence shifted from the normal point 655° C. or 1211° F. down to 620° C. or 1148° F., and in the latter case it was difficult to detect. The behaviour of the chromium steel is therefore similar to that of carbon steel; but the shifting of the points of recalescence is much exaggerated in degree, the remarkable fact being that fusion restores the power possessed by the steel of undergoing molecular change. The curves numbered 1, 2, and 5, represent other variations due to the initial temperature.

These facts were observed quite independently by Osmond and by myself. The explanation of them would appear to be closely connected with the solution in the mass of metal of a hard compound of chromium, carbon, and iron, the solubility of the compound varying with the temperature to which the mass has been raised. Osmond is perfectly justified in considering that in the absence of carbon the presence of chromium does not maintain the iron in the β or hard condition. We know too little as yet about the chromium steels to enable wide generalizations to be made. It is important however to note that the atomic volume of chromium is nearly the same as that of iron, and its influence ought not to be great. It is to be hoped that the use of the electrical furnace which has now been provided for the purposes of this investigation will enable a quantity of pure chromium to be prepared.* The relations of this interesting metal to carbon and to iron may then be studied with advantage.

Autographic Recording Pyrometer.—This instrument was described in the first Report to the Committee; but as the investigations progressed it soon became evident that the construction of many of the details could be greatly improved; and, in order that a more perfect instrument might not be wanting, the appliance of which the following is a description was made at the Royal Mint by artificers from the Royal Arsenal, Woolwich, who were permitted by Dr. Anderson, Director-General of Ordnance Factories, to undertake its construction for use in his department. As shown in Figs. 10 to 17, Plates 28 to 30, it consists of a camera about five feet long, in which the galvanometer may be placed in either of two positions according to the range of temperature to be observed; the nearer position is for observing large ranges, and the further for small ranges. This camera has three doors, and is made separate from the portion of the apparatus which contains the moving photographic plate. The two parts are connected by a flexible leather "bellows" junction J, the object being to enable the plane of the sensitized plate to be adjusted at right angles to the ray of light from the stationary galvanometer mirror F. Inside the camera is a focussing tube T, containing a lens L, which receives the light from the mirror H, and transmits it to the galvanometer mirrors F and M. Of these mirrors M is movable, and is carried by the coil of the galvanometer; while F is stationary on an adjustable arm fixed to the supports of that instrument, its function being to send a ray of light from the mirror H to the slit AB, and thus to trace a datum line as the photographic plate travels upwards. The temperature is recorded, as described in the last Report, by the variations in the position of the spot of light derived from the movable mirror M. There is a screen S to cut off light reflected from the brass work of the galvanometer. The end of the tube T is provided with an adjustable brass slit, by means of which the width of the photographic traces on the plate can be varied. The mirror H is mounted on a block, which can be adjusted so that external light may be brought from either side. The focussing of the lens L may be effected from outside the camera. Plug connections are provided at the top of the instrument, and the wires *a b* connect the galvanometer with the thermo-junction at the source of heat. The photographic plate is secured to its carrying slide C by means of little cams, and the carrier C is enclosed in a case K, provided with a light-tight door N. The case K is held in position by a pin P. The connection of the photographic plate with the driving clock is shown at D. The sensitized plate moves in front of the slit AB, and is lifted by a weight actuating a fine clock, constructed for the Institution by the well-known horologist Mr. David Glasgow. It may be mentioned that the galvanometer stands on three plates, which provide the well-known combination of the hole, slot, and plane, for steadiness. With the aid of this instrument several hundred plates of curves have been prepared; and these it is hoped will be useful in the course of the investigation.

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* Moissan, Comptes Rendus, vol. cxv. 1892, pp. 1031 and 1034.

In drawing this Report to a conclusion, I would thank Mr. Jenkins and Mr. Stansfield, whose assistance the Institution has given me in conducting these investigations. The experiments have demanded great care; and both have worked admirably, sparing no efforts to make the results trustworthy. In Mr. Jenkins I have had the advantage, seldom to be secured in physical work, of the mechanical skill and knowledge of a trained engineer whose aid has been of much value.

General Conclusions.—It may be asked, what evidence has been gathered as to the mode of action of added elements? and does it appear that the atomic volume of the added element has a dominating influence on the mechanical properties of the mass in which it is hidden? In attempting to answer these questions, it must be remembered that in the earlier experiments pure gold was the basis of examination; and that the evidence in favour of the above view was shaken only by the somewhat abnormal behaviour of aluminium and lithium, which made gold rather stronger than the volume of their atoms warranted if the theory held good. Some recent experiments [*] of my own however have shown that the relations of aluminium and gold are very peculiar, if not unique. Aluminium in solution does not behave as if its atoms were single; so that it is doubtful what the atomic volume of aluminium really is. I would also point out that, quite apart from the evidence furnished by the experiments on gold, independent testimony as to the influence of the atomic volume of an added element is afforded by Osmond's work, which shows that the presence of elements with a large atomic volume accelerates the change of β or hard iron to the α or soft variety, while elements with a small atomic volume delay the change. In the case of copper, grave complications arise from two causes. First, it is doubtful whether the copper does or does not exist in more than one state; and the passage of the metal from one state to another may be determined by the presence of an added element. Second, it is difficult to ensure that a small quantity of an added element should remain unoxidized in the mass of copper—a difficulty which is of far less magnitude in the case of the experiments with gold. The true action of an added element may thus readily be masked by its action as a deoxidizer. Notwithstanding these difficulties, it is undoubtedly proved that bismuth, potassium, and tellurium—all of which have large atomic volumes—greatly lower the tenacity of copper. Arsenic, which has a larger atomic volume (13·2) than copper (7·1), confers strength on copper; but it is very certain that the limit of elasticity and the ductility of a metal are greatly influenced by the presence of such of the elements with large atomic volumes as have thus far been studied; and this fact may be of more molecular significance than the diminution of tenacity, to which, for the sake of simplicity, attention was mainly directed when the early experiments on gold were made.

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[*] Proceedings of the Royal Society, 1891, vol. 49, p. 347; and 1892, vol. 50, p. 367

The very important question now arises, may the effect of an added element mainly depend on its power of forming either a fusible or an infusible compound with the mass in which it is hidden? M. André Le Chatelier * suggests that this is the case, and that the deleterious action of an element is due to its forming a fusible compound with the mass; whilst, on the other hand, the presence of an element which forms an infusible compound with the mass promotes the formation of a fine grain and gives strength. I would point out however that, if this should prove to be the case, it would not remove

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* Le Génie Civil, 1891.

the action of the added element from the operation of the periodic law; for there is much evidence in favour of the view that "the properties of *compounds* of the elements are a periodic function of their atomic weights." It must be remembered, as against the view of this skilful worker, M. André Le Chatelier, that the whole tendency of recent work, especially that of Heycock and Neville, and my own, is to show that, when small quantities of elements are added to a metallic mass, they behave as a gas would, and remain free; and the results given in this Report in the case of bismuth fully confirm this view. W. Spring has recently discussed the possibility that metals when reduced from volatile chlorides remain in an allotropic gaseous state at temperatures below their fusing points.* It remains to be seen at what point, in the cooling of a highly heated fused mass of a metal forming a solvent, an impurity would enter into combination with a portion of the mass, and what amount of impurity of a given kind has to be present in order that it may lose its individuality. If the fusibility of a free added element were the determining cause of its action, it should be possible to classify the impurities in gold in the order of their fusibility; but any such attempt breaks down hopelessly. To turn once more to the action of aluminium on gold, if a small quantity of aluminium did enter into combination with a large excess of gold, it may fairly be urged that it would tend to form the very fusible gold-aluminium alloy which contains 10 per cent. of aluminium, in preference to the singularly infusible one containing 22 per cent. On the other hand, the most remarkable case known of the production of a very fine-grained structure, in a mass which under ordinary conditions naturally solidifies in large crystalline planes, is presented by the action of a small quantity, $\frac{1}{2}$ to 1 per cent., of tellurium on bismuth; but, as 1 per cent. is a large addition, the telluride of bismuth $BiTe_3$ is probably formed, and it is not readily fusible, for its melting point is at 360° C. or 680° F.

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* Journal of the Chemical Society, April 1893, abstracts vol. ii. p. 168. Zeitschrift für anorganische Chemie, vol. 1, p. 240.

With regard to the important molecular change which may take place in a solid metal or alloy, and of which the recalescence of steel is the most striking example, it is no small gain to have ascertained that the temperatures at which such changes occur are altered by pressure; and this seems to be a conclusion which it is safe to deduce from the experiments given in the present report.

The profound change which is produced in the properties of metals by alloying them is well shown by some recent experiments by Professors Dewar and Fleming.* They have examined the effect of very low temperatures on the electrical resistance of pure metals and alloys; and the results tend to prove that, if pure metals could be reduced to the absolute zero of temperature, they would offer no resistance to the passage of an electric current. This is true of soft pliable metals like gold, and rigid ones such as nickel. Impure metals and alloys behave very differently; the diminution of resistance by exposure to cold is very marked, but the direction of the curves representing resistance and temperature appears to indicate that the resistance at the absolute zero of temperature would still be considerable.

I would remind the members of the Institution of the nature of the work the Alloys Committee has undertaken. It is nothing less than the investigation of the fact which has been recognized for centuries, that " traces " of elements profoundly affect the properties of masses of metals. " Traces " may either confer on metals qualities which are most precious for industrial purposes, or may reduce them, through various stages of comparative unsuitability, to absolute worthlessness. It will thus be seen that the Alloys Committee is examining one of the most subtle actions in nature.

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* Philosophical Magazine, vol. xxxiv. 1892, p. 326.

For Discussion see pages 145–198.

Appendix.

Determination of Bismuth in Copper.—In order to determine the amount of bismuth present in copper, a weighed portion of the alloy is dissolved in nitric acid, the solution is diluted with water, and heated to nearly the boiling point. An excess of ammonium carbonate is then added, until the copper, at first precipitated as carbonate, is all re-dissolved, and the solution assumes a clear blue colour. It should now smell slightly of ammonia, and be kept nearly at the boiling point for from eight to twelve hours, at the end of which time the bismuth will be completely precipitated.

The precipitate is then collected on a filter, and washed by a hot dilute solution of ammonium carbonate, until it is quite free from copper salts. After careful drying and ignition, the bismuth is weighed as oxide, Bi_2O_3. The copper present in the filtrate may be determined by titration with a standard solution of hyposulphite of soda.

Copper Fire-box Plate.—Analysis of a sample of copper plate taken from the side of the fire-box, near the expansion-bracket, of No. 49 locomotive on the Metropolitan Railway. This engine had been running for twenty years and a half from 1870, and had covered 500,000 miles.

Copper	98·7000	per cent.
Silver	0·0346	
Gold	0·0001	
Lead	0·4085	
Arsenic	0·3726	
Antimony	0·0346	
Bismuth	0·0360	
Iron	0·0069	
Nickel	0·3039	
Cobalt	nil	
Oxygen	0·0181	
Phosphorus	nil	
Sulphur	0·0064	
	99·9217	per cent.

TENSILE TESTS AND CHEMICAL ANALYSES OF COPPER PLATES FROM FIRE-BOXES OF LOCOMOTIVES ON THE GREAT WESTERN RAILWAY.

By Mr. WILLIAM DEAN, Member of Council,
Locomotive Superintendent, Great Western Railway.

Considerable differences having been found in the durability of Copper Fire-boxes in Locomotives on the Great Western Railway, which could not be accounted for by differences in the conditions of working, it was decided to commence testing and analyzing samples of copper from fire-boxes which had run long mileages, and from others which had run short mileages only. Up to the present time, March 1893, eighteen samples have been selected; and the results of the tensile tests and chemical analyses are given in the following Tables 2 and 3, pages 140–143.

The number of samples examined being comparatively small, and the results wanting in uniformity, it would probably be unsafe to form from these tests any decided conclusion as to the best composition for copper fire-box plates. It would appear however that the presence of a small percentage of arsenic is in no way detrimental to the lasting quality of the plates.

The testing machine used for the tensile test is a compound-lever horizontal machine of Tangye's pattern with hydraulic cylinder. In making these tests the pressure was applied by hand-pumps. The test pieces were sheared out of the plate, straightened by hammering cold, and planed to the dimensions shown one quarter

(*continued on page* 144.)

TABLE 2 (*continued on next page*).

Tensile Tests of Copper Plates from Fire-boxes

No. of Sample.	Locomotive.		Working Pressure of Steam. Lbs. per square inch above atmosphere.	Description of Plate.	Thickness of Plate when new.
	No.	Description.			
			Lbs.		Inch.
*1	15	4-wheels Goods, Tank . .	130	Tube	7-8
2	330	5 feet Coupled, Goods, Tender .	140 to 120	Tube Side	— —
3		New Plate	—	Tube and Back	—
†4	818	6 ft. 6 ins. Coupled, Passenger .	140	Side	—
5	176	4-wheels Coupled, Goods, Tender	130 to 120	Tube	—
6	237	5 feet Coupled, Goods, Tender .	130 to 120	Tube	—
7	2211	6 ft. 6 ins. Coupled, Passenger .	140	Side	half-inch
8	510	5 feet Coupled, Goods, Tender .	140	Tube	3-4 & half
9	1205	Do.	140	Side	half-inch
10	543	5 feet Coupled, Passenger, Tank	140	Tube	3-4 & 3-8
‡11	183	5 ft. 9 ins. Coupled, Passenger .	140	Back	9-16
12	979	5 feet Coupled, Passenger, Tank	140	Tube	half & 5-8
13	986	Do.	140	Tube	half & 5-8
14	929	4 ft. 6 ins. Coupled, Goods, Tender	140 to 120	Tube	7-16 & 5-8
15	809	6 ft. 6 ins. Coupled, Passenger .	140	Tube	7-16 & 5-8
16	978	5 feet Coupled, Passenger, Tank	140	Tube	half & 5-8
17	462	Do.	140	Tube	7-16 & 5-8
‡18	19	6 feet Coupled, Passenger. .	140	Tube	3-4

* Drillings for analytical purposes only. † Badly corroded. ‡ Badly cracked.

(*continued from preceding page*) TABLE 2.

of Locomotives on Great Western Railway.

No. of Sample.	Date when Plate was		Mileage.	Tensile Test.		
	put into Fire-box.	taken out of Fire-box.		Breaking stress per sq. inch on Original Area.	Contraction of Area.	Elongation.
			Miles.	Tons.	Per cent.	Per cent.
*1	— 1847	— * 1886	463,660	—	—	—
2	— 1864	— 1884	489,334	15·06 14·89	52·72 49·53	40·62 37·50
	— 1864	- 1884	489,334	14·96 14 90	40·53 37·59	40·62 36·71
3	— 1884	..	0	—	—	—
†4	Dec. 1882	April 1887	177,633	—	—	— †
5	Nov. 1864	Aug. 1886	493,994	14·73	52·73	41·16
6	Nov. 1865	Aug. 1885	427,102	14·61 13·56	49·41 57·44	44·78 S 36·25 T
7	July 1882	Dec. 1888	223,801	—	—	—
8	May 1886	Jan. 1889	72,676	13·44	41·59	36·45
9	June 1876	Jan. 1889	295,574	14·78	60·43	43·40
10	Mar. 1869	May 1890	441,744	14·50	48·20	42·70
‡11	June 1887	May 1890	72,247	14·47	40·10	30·41 ‡
12	Oct. 1874	June 1890	485,004	14·94	55·83	47·65
13	Nov. 1874	Oct. 1890	506,341	14·40	49·42	33·98
14	Mar. 1874	Dec. 1890	414,185	14·50	51·56	39·32
15	May 1873	Jan. 1891	537,500	13·79	52·23	33·06
16	Oct. 1874	Nov. 1890	427,296	14·90	52·73	35·28
17	Feb. 1869	Nov. 1890	512,092	14·07	50·39	32·28
‡18	Oct. 1890	April 1892	54,564	13·73	43·28	34·70 ‡

* Fire-box still working. S=Slotted. T=Turned.

TABLE 3 (*continued on next page*).

Chemical Analyses of Copper Plates from Fire-boxes

No. of Sample.	Mileage.	Antimony.	Arsenic.	Bismuth.	Cobalt.	Iron.	Lead.	Manganese.
	Miles.	p. cent.	p. cent.	p. cent.	p. cent.	p. cent.	p. cent.	p. cent.
*1	463,660	0·005	0·262	0·009		0·006	0·090	
2	489,334	0·006	0·534	0·007		0·022	0·051	
3	0	0·002	0·020	0·020	0·000	trace	0·020	0·000
†4	177,633	trace	0·013	0·009		trace	0·043	
5	493,994	0·009	0·811	0·043		0·020	0·081	
6	427,102	0·004	0·017	0·018		0·011	0·113	
7	223,801	0·006	trace	0·063		0·014	0·381	
8	72,676	trace	0·069	0·004			0·036	
9	295,574	trace	0·115	0·013			0·135	
10	441,744	0·008	0·050	0·005	0·000	0·007	0·268	0·000
‡11	72,247	trace	0·042	trace	0·000	0·006	0·126	0·000
12	485,004	0·010	0·059	trace	0·000	0·008	0·096	0·000
13	506,341	0·014	0·292	0·004	0·000	0·011	0·126	0·000
14	414,185	0·005	0·060	0·004	0·000	0·009	0·165	0·000
15	537,500	0·004	0·039	0·008		0·002	0·189	
16	427,296	0·005	0·191	0·037	0·000	0·010	0·122	0·000
17	512,092	0·006	0·021	0·023		trace	0·222	
‡18	54,564	0·005	0·042	0·012		0·004	0·056	

* Drillings for analytical purposes only; fire-box still working.

(*continued from preceding page*) TABLE 3.

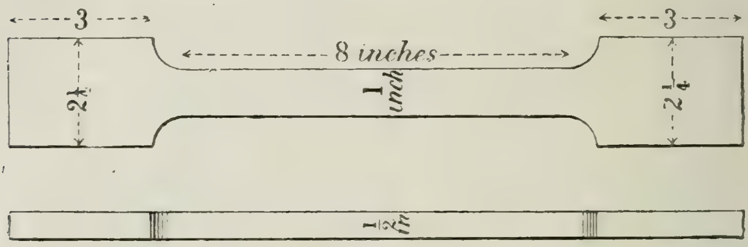
of Locomotives on Great Western Railway.

Nickel.	Phosphorus.	Silver.	Sulphur.	Tin.	Zinc.	Oxygen combined.	**COPPER.** 1–7 by difference, D; 8–18 by direct test, T.	Date of Analysis being made.	No. of Sample.
p. cent.	p. cent.	p. cent.	p. cent.	p. cent.	p. cent.	p. cent.	p. cent.	1884–93	
0·044		0·071	0·000	0·027	0·000		D99·486	Jan. 88	*1
0·094		0·015	0·000	trace	0·000	0·076	D99·195	May 88	2
0·070	0·000	0·010	0·000	0·020	0·000	0·020	D99·818	Dec. 84	3
0·055		0·024	0·000	0·009	0·000	0·019	D99·828	Jan. 88	†4
0·083		0·007	0·000	trace	0·000	0·045	D98·901	Jan. 89	5
0·080		0·041	0·000	trace	0·000	0·044	D99·672	Jan. 89	6
0·181	0·000	trace	0·000	0·000	0·000	0·077	D99·278	Mar. 89	7
	E = 0·171 per cent.					0·070	T99·650	Dec. 89	8
	E = 0·132 per cent.					0·095	T99·510	Dec. 89	9
0·110	E = 0·049	0·011	0·014		0·000	0·248	T99·230	Apr. 93	10
0·060	E = 0·016 per cent.			0·000	0·000		T99·750	Mar. 93	‡11
0·136	E = 0·061 per cent.			0·000	0·000		T99·630	Mar. 93	12
0·067	E = 0·032	0·014	0·016		0·000	0·174	T99·250	Apr. 93	13
0·173	E = 0·144 per cent.				0·000		T99·440	Apr. 93	14
0·026	E = 0·042 per cent.						T99·690	July 92	15
0·112	E = 0·051	0·011	0·015		0·000	0·136	T99·310	Apr. 93	16
0·055	E = 0·043 per cent.						T99·630	July 92	17
0·015	E = 0·056 per cent.						T99·810	July 92	‡18

† Badly corroded. ‡ Badly cracked. E = Elements not separately determined.

(*continued from page* 139.)

full size in the following sketch, so as to have a uniform sectional area of half a square inch throughout the length tested of eight inches.



Some of the samples have been tested for electrical conductivity by the kindness of Mr. R. E. B. Crompton; and the results are shown in Table 4, both when the copper was unannealed and also when annealed.

TABLE 4.

Electrical Conductivity.

Sample No.	Unannealed. Per cent.	Annealed. Per cent.
1	67·20	66·53
4	69·95	69·61
5	22·28	
11	63·01	62·70
12	65·66	65·09
13	47·60	47·31
14	69·26	68·68
18	78·10	78·30

For Discussion see pages 164–198.

Discussion.

Professor Roberts-Austen thought the members present would like to have some visible evidence of the kind of experiments in which the thermo-couple was used; and therefore, although the few experiments that he had to show did not really go beyond the limits of the report read at the former meeting, yet, as they had not on that occasion been experimentally demonstrated, it might be well to show them now. The horizontal scale 30 feet long, fixed upon the wall, was graduated in centigrade degrees from zero up to above the melting point of palladium, that is above 1,500° C. or 2,730° Fahr. The galvanometer here used was merely a delicate dead-beat instrument, in which the ordinary magnetised needle was replaced by a coil hanging freely between two magnets, being suspended between two vertical wires, on one of which was fixed a mirror. The current which passed through these suspending wires and round the coil was developed by heating the thermo-junction, the nature of which had previously been explained: it consisted of a wire of platinum, twisted together with one of platinum containing ten per cent. of rhodium, so that if the junction were heated it would produce a deflection of the coil, and consequently of the mirror; and the amount of deflection was found to be proportional to the heat applied to the junction. The ray of light thrown upon the scale from the mirror would track its course along the scale to the extent of the deflection of the mirror. The two wires forming the thermo-junction were placed in the bottom of a little cup, in which a globule of the metal to be examined was melted over them by means of an oxy-hydrogen blow-pipe. The globule of metal had to be placed in close proximity to the thermo-junction, almost touching it, separated by only the slenderest layer of clay; otherwise sufficient sensitiveness would not be obtained to give accurate indications. On the other hand the sensitiveness obtained in this way was attended by the risk of an accident through the fusing of the junction itself, which was of frequent occurrence; hence the difficulty of showing these experiments out of the laboratory. They

(Professor Roberts-Austen.)

were indeed most precarious, even under the most favourable conditions; time after time they would go on well, and then a whole series might fail. A rough calibration of the scale would first be shown, by putting into the cup a globule of palladium, and gradually heating it up. (Experiment shown.) The melting point of palladium was about 1,500° C. or 2,730° Fahr.; and it was seen that the spot of light had been allowed to travel somewhat above that temperature on the scale, because it was necessary to make quite sure that the metal was thoroughly melted before it was allowed to begin to cool. Then on the removal of the blow-pipe, as the molten metal began to cool down, the spot of light began to travel backwards along the scale, until the moment that it reached the melting point. Here it was seen to make a sudden halt, and to remain quite stationary during the ten or twelve seconds occupied in the solidification of the metal. As soon as the whole mass had become solidified, the spot began to move again, and continued to travel backwards along the scale as the solid metal cooled down. The worst of palladium was that it absorbed oxygen so freely during heating as to necessitate heating it up well above the melting point, in order to drive off all the oxygen, because the thermal properties of the metal itself were disturbed by the absorption of gas and formation of oxide. There was therefore some danger of fusing also the thermo-junction underneath the melted palladium; and in an attempt to repeat the same experiment, so as to show the halt still more clearly by heating the metal well above the melting point, this risk was unfortunately exemplified by the failure of the thermo-junction through fusion.

With gold, which did not absorb oxygen like palladium, and consequently did not suffer disturbance of its thermal properties by solution of gas, the halt in cooling was somewhat longer, and therefore easier to observe; but there was the same liability to fuse the thermo-junction at the high temperature requisite to melt the metal. (Experiment shown.) With gold 1,045° C. cr 1,913° Fahr. was the melting point; and after it had been heated above this temperature, it was seen that in cooling again the spot of light halted sharply at the solidifying point, and paused there until all the metal had become solid; after which it resumed its backward course along the scale as the solid gold cooled down.

The experiment was then repeated in a modified form, enabling the cooling curves to be traced, first of pure gold, and then of gold rendered impure by a little aluminium: so as to show the way in which the curves were traced in the autographic recorder. For this purpose, the same button of gold being again melted, the galvanometer ray was thrown upon a sheet of paper made to travel vertically at a fairly uniform rate of about two inches in five seconds by hand power, instead of by means of a falling weight as was usual in the case of the experiments described in the report. Every five seconds the centre of the spot of light was carefully marked by hand upon the paper. (Experiment shown.) On joining the points so marked, it was seen that the cooling curve of gold thus drawn, shown by the full line in Fig. 23, Plate 36, had not so sharp a halt at the point of solidification as the curve of pure gold would have. The reason was simply that in this experiment the button of gold had been rendered somewhat impure by the fact that it had taken up a little of the platinum from the fused junction in a repetition of the previous experiment. The nearly horizontal part of the curve, occurring during the time of solidification, represented the latent heat which was coming out of the fused metal as it solidified, and was thereby maintaining its temperature constant. It was just the same process that occurred during the freezing of water into ice, or the condensation of steam into water. If the gold were perfectly pure, the angle at the halt would be quite sharp; but practically even the purest gold contained a minute trace of silver, which had the effect of slightly rounding the angle.

The effect of adding a little aluminium to pure gold was to round off the angle of the halt still more, as shown by the dotted line in Fig. 23, and to do away altogether with the horizontal part of the curve, thus producing a curve resembling that obtained in the cooling of pitch, devoid of any definite stage of solidification and passing through a prolonged period of pastiness. The fresh globule of gold now used was very pure, never having been contaminated with platinum from the thermo-junction, as had been the case with the button of gold in the preceding experiment. As soon as the gold was melted, a minute particle of aluminium was added, not more than 0·1 or 0·2 per cent., which nevertheless would so entirely change the nature of the gold that it would cool like pitch instead of like ice. The aluminium having been added, the melted gold was heated up again, to insure thorough mixture and complete melting of the whole.

The President asked whether the aluminium diffused itself through the gold, without the need of stirring.

Professor Roberts-Austen replied that it did so, and with great rapidity. (Experiment shown.) From the cooling curve now obtained, as shown by the dotted line in Fig. 23, Plate 36, by tracing the spot of light in the same way as in the previous experiment and on the same piece of paper, it was seen that the sharp angle of the halt in pure gold was not obliterated altogether, but was replaced by a gentle bend; and that the nearly horizontal part of the previous curve had here disappeared almost wholly, being replaced by a continuous downward slope. The previous curve interrupted by the halt at solidification, as shown by the full line, was similar to that obtained with ice; while the curve shown by the dotted line corresponded with that which would be given by pitch.

In Fig. 24, Plate 36, was shown a cooling curve traced by hand in a similar way from a piece of rather highly carburized steel; the recalescence while solidification was taking place was here very distinctly marked, and the whole history of the piece of steel during cooling was clearly recorded.

The President asked whether this was the way in which M. Osmond's curves of the cooling of steel had been traced.

Professor Roberts-Austen said it was not so. The travelling sensitized plate had not been used by M. Osmond, whose curves were plotted from the observed rate of motion of the spot of light along the scale of temperature; they were therefore not autographic curves.

Professor ALEXANDER B. W. KENNEDY, Vice-President, said one result of the difficult and highly important investigations described in the report, which had been carried out in so remarkable a manner, was that Professor Roberts-Austen had now given engineers a new apparatus for aiding such investigations; and although as yet they had not by any means learnt all the use that could be made of it, he hoped that even those who were not so skilful as Professor Roberts-Austen might nevertheless be able to handle it in a satisfactory manner.

In connection with the view set forth in page 103, that the molecules of small quantities of elements distributed through a mass of a solvent retained their individuality, remaining free, and not entering into combination with the mass, he supposed no suggestion was thereby implied that they were not fairly and uniformly distributed throughout the whole mass; for however small their proportion might be, it would still be expected to find the same proportion in any part of the mass that might be examined.

In connection with Mr. Herbert Tomlinson's investigation (page 105) there appeared to him to be some points specially interesting to mechanical engineers. It was stated that ten years ago he had given a table showing the relation of the ordinary modulus of elasticity to the atomic volume of metals, and had concluded that the divergences shown by several metals from a certain mean value arose from the fact that the presence of small amounts of impurity made an enormous difference in the elasticity. There was one fact however that had struck himself pretty frequently, which perhaps did not quite corroborate this conclusion: namely that the modulus of elasticity of nearly all qualities of wrought-iron and steel—from Swedish iron, which was the nearest approach known in practice to absolutely pure iron, up to steel containing about one-half per cent. of carbon—was very nearly the same. He remembered being much surprised at first that this was so, although he believed it was well known before he happened to become acquainted with the fact. But an enormous reduction in the modulus was met with when the carbon rose to 1 or $1\frac{1}{2}$ per cent., which was something like its percentage in cast-iron.

Below the half per cent. the modulus of elasticity throughout the whole range of the ordinary steels remained fairly constant; the small differences which no doubt did occur were much less than it would have been expected to find, especially in view of the extraordinary way in which small quantities of impurity affected certain other properties of the metal.

The experiment illustrated in Fig. 1 was really one of the most curious that had ever been described (page 106). It was apparently using a piece of glass as a sieve to filter out molecules. Why they got so filtered out, he hoped Professor Roberts-Austen would explain a little more fully. From the account given (page 107) of Tegetmeier's experiment, it looked as if the process had been a kind of step by step replacement of the sodium in the glass by sodium from the sodium amalgam, and in the second case by lithium from the lithium amalgam, until finally molecules of the metal from the amalgam had passed right through the glass into the mercury on the other side. This process however seemed hardly quite consistent with the charming conception that a number of tracks or molecular galleries were left in the glass by the sodium atoms, along which certain other atoms could not pass because they were too big. Did Professor Roberts-Austen really mean this? because it was almost too marvellous to think that a passage could really exist just large enough to let one molecule through, and not quite large enough to let another through. Was it really a physical passage that went the whole way through the glass?

Professor Roberts-Austen said the word "galleries" was not his own, but if he remembered rightly Tegetmeier's, who compared the pores to worm-holes.

Professor Kennedy asked what was intended by the statement in page 108, that there seemed to be little doubt that copper could be prepared by electrolytic deposition in an allotropic state, in which the density of the metal was only from 8·0 to 8·2, as compared with 8·92 for normal copper. Was this a real altered density which depended on the alteration of the atomic volume? or was it only a density depending on the mean distance between the centres of gravity of the molecules? That is to say, was the real substance of which the electrolytic copper consisted any less dense? or was the copper itself always of the same density, and simply in an opener or more porous condition in the electrolytic variety? Having himself tried hard in a number of experiments to condense ordinary iron or steel, he had never found within the limits of error of the experiments that any such result could be brought about at all. The same weight always occupied the same volume; but no doubt that might be because the experiments were not delicate enough. It would indeed be most curious, if it were actually possible to get the same substance of two entirely different densities, when in the form of the smallest particle into which the substance could possibly be subdivided.

For the conductivity of copper a standard was at present taken which was called 100 per cent.; and yet all the first-class makers were now able to produce a metal which had a conductivity of 1 or even 2 per cent. more, which always seemed a little awkward. Mention was made in page 112 of singularly pure copper having the high conductivity of 102. He wished that Professor Roberts-Austen or someone else in authority would replace the present standard by a more rational one, which should truly represent perfection, and be incapable therefore of being surpassed in practice. The existing standard he supposed merely meant that the pure copper of thirty or forty years ago was not as pure as the copper which could be made at the present time.

In Table 1 (pages 114–118) he thought the column headed "tensile strength per square inch on final area" was perhaps not of much value. From the description given of the testing (page 113) he gathered that what had actually been done was that the maximum load on the lever of the testing machine had been taken upon the smallest sectional area of the test rod just before it began to constrict locally, and therefore not upon its final area. If the exact moment could with certainty be picked out just before the rod began to constrict locally, and if the non-constricted sectional area at the same instant could be measured accurately, the figures so

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obtained would of course be of some value; but from a good many experiments which he had made of the same kind, he knew this was very difficult, and he rather thought, unless corrected by Professor Roberts-Austen, that the figures given in this column in the table were not so determined as to be of real scientific value. In this opinion he was the more confirmed, because the figures in the column referred to (pages 116 and 117) were very irregular, whereas the figures of tensile strength on the original area were practically as regular as any such figures could be expected to be in experiments of that amount of difficulty. It would be seen in page 116 that the tensile strength per square inch on the final area ranged from 69,300 lbs. down to 23,190 lbs., whereas on the original area the fluctuations were only from 30,920 lbs. down to 20,990 lbs., the latter results thus being fairly regular. There was of course a method of getting the true stress per square inch on the true final area, by so reducing the load on the test piece while constriction was going on as to keep the steel-yard always floating, even after the maximum load had been passed. This indeed was not easy to do, and with some machines not even possible; and he understood that it had not been done in this case. Probably however it was the only way of getting the real stress at the instant of fracture in a material which constricted sensibly.

In offering these few general remarks, his simple desire was to elicit some further observations from Professor Roberts-Austen later on. He wished also to give some expression to his own strong sense of the great value from a scientific point of view, and ultimately from a technical point of view, of the investigations in which the author was still engaged.

Professor J. O. Arnold, Sheffield, had read Professor Roberts-Austen's second report to the Alloys Research Committee with great interest and pleasure. No one could admire and appreciate more highly than he did the labour and thought which had been expended during the last eighteen months in obtaining the results now laid before the Institution; and he wished to congratulate the author upon the exceedingly practical and utilitarian nature of the bulk of the report.

As a contribution to the practical metallurgy of copper, it must in the future be particularly valuable to engineers and to students. That portion of the research which had reference to the influence of small quantities of bismuth in copper was of special importance; and he fully agreed with the author's claim that only by the system of photographic pyrometry developed by him could the remarkable results recorded have been obtained. At the same time the statement on page 123, that because the metal was highly crystalline it was consequently intensely brittle, he could not admit to be invariably true. For instance, the most crystalline structure met with in iron and steel metallurgy was that of pure wrought-iron, a substance remarkable for its ductility. Professor Roberts-Austen's law of atomic volumes, he fully admitted, had in the cases of metals like gold and copper a solid foundation; but in its application to iron the theory, as tested by every-day practical results in the steel shop, in his opinion utterly broke down. The most important metallurgical industry of this country was that of iron; and it was now emerging from the obscurity of governance by rule of thumb into the light of science. At this critical stage it was of the highest importance that practical men should be enabled to feel a sense of security in scientific guidance. He was therefore compelled to protest against the enunciation of a theory, however qualified, that chromium, tungsten, and silicon softened steel, when it was known from the results of daily practical experience that the introduction of these elements in the presence of carbon had a remarkable hardening effect. But a theory even more injurious was continually referred to in the present report as being probably true: namely Osmond's theory of β or hard iron, against which he had already protested in the discussion upon the first report to the Alloys Committee. That theory briefly stated was that the hardness of steel depended, not upon the carbon to any great extent, but upon the production of an allotropic modification of iron of adamantine hardness: so that, if the theory were carried to its logical conclusion, there should be nothing to prevent a bar of wrought-iron under suitable physical conditions from making an excellent turning-tool for chilled rolls. The main foundation upon which that theory rested was that, during

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the cooling of a piece of iron, there occurred at a temperature between 850° and 900° C., or 1,560° and 1,650° Fahr., an abnormal but minute evolution of heat, indicating one of what were known as the critical points of iron and steel. During the eighteen months which had elapsed since the presentation of the first report to the Research Committee of this Institution, he had been engaged, with the assistance of Mr. Joseph Jefferson, the demonstrator at the Sheffield Technical School, than whom Professor Roberts-Austen had turned out few more capable students, upon a tedious and minute study of the thermal phenomena which occurred during the heating or cooling of steel between the temperatures of 600° and 1,000° C., or 1,100° and 1,800° Fahr. The details of the results of those investigations he purposed publishing; and meanwhile he had much pleasure in acknowledging the valuable guidance of Professor Roberts-Austen's first report with reference to the preparation of the apparatus by means of which these observations had been made. Whilst adopting however what was obviously good in the apparatus used by M. Osmond and Professor Roberts-Austen, he had himself introduced certain modifications which seemed to him necessary for obtaining true results: firstly, a means of registering more delicately the thermal changes occurring; secondly, the employment of larger pieces of steel; and thirdly, a furnace arrangement by means of which the reversibility of the critical points in cooling and heating could be accurately measured, the results obtained by M. Osmond having been somewhat erratic in this particular. These modifications had proved successful in obtaining a scale of about 4° C. per millimetre for the deflection of the galvanometer at the critical points, equivalent to about 1° Fahr. per 1–200th of an inch. The pieces of steel experimented upon weighed each 415 grammes or 0·915 lb. The delicacy of the apparatus was indicated by the fact that during cooling the temperature of the piece of steel rose in certain instances as much as 25° C. or 45° Fahr. at a critical point, while during heating actual falls of temperature were sometimes registered in high steels.

In response to a suggestion he had offered in the discussion upon the first report, that use should be made also of the microscope in these researches, Professor Roberts-Austen had explained that the pyrometer had been employed, and not the microscope, because the changes under investigation were molecular. The correlation however of the pyrometric results with the microscopical examination of the samples under investigation had revealed a number of facts in connection with the critical points during the cooling of iron and steel, which seemed to have escaped the observation of M. Osmond and Professor Roberts-Austen. These points of recalescence, it might be remembered, were three in number,* namely: a point Ar1 occurring between 650° and 700° C., or 1,200° and 1,290° Fahr.; a point Ar2 occurring about 700° C. or 1,290° Fahr.; and a point Ar3 occurring between 850° and 900° C., or 1,560° and 1,650° Fahr. In the observations of M. Osmond and Professor Roberts-Austen the evolution of heat at the intermediate point Ar2 was so minute that it was regarded by M. Osmond as merely a tail end of Ar3; while from the absence of any allusion to it in the remark at the top of page 128 in the present report he was led to infer that its existence as a true critical point was regarded by the author as somewhat apocryphal. Nevertheless the results of his own investigations at the Sheffield Technical School appeared to indicate that in the theory of β iron the proof of the existence of a molecular change in iron must in future be based upon this very point Ar2. A number of chronographic curves obtained from steel low in carbon, in which alone this intermediate evolution of heat could be observed, showed that it had no connection with the higher point Ar3, and moreover that it possessed a peculiarity which distinguished it from either of the two other points Ar1 and Ar3. In the record book of curves which he had the pleasure of exhibiting, it would be clearly seen that the points Ar1 and Ar3 possessed the property noted in page 129 of the report in connection with Newton's alloy, namely they were not truly

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* The nomenclature used throughout this discussion differs only in type from M. Osmond's original, and sounds the same to the ear: A stands for *Arrêt* or halt; r for *refroidissement*, or equally well for recalescence during cooling; and 1–2–3 denote the sequence of the three points as they occur in the ascending order during heating, the first being the halt at the lowest temperature and the third the halt at the highest.

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reversible, but appeared during heating at a temperature from 20° to 40° C. or from 35° to 70° Fahr. higher than during cooling; whereas the point Ar2 appeared at practically the same temperature during both cooling and heating, or, if anything, at an average of a few degrees lower during heating. This important fact having been ascertained, the question arose, to what causes were these three marked evolutions of heat during cooling to be attributed? With regard to the lowest point Ar1, it was generally admitted by iron and steel metallurgists to be due during cooling to the combination, and during heating to the dissociation, of carbon and iron in the form of Abel and Müller's compound CFe_3. The truth of this idea had been fully confirmed by the microscopical results obtained. As the magnitude of the bulge in the curve increased with the carbon, so also did the area of Sorby's laminæ grow in the respective microscope sections. The materials upon which the investigation of the properties of the two other points Ar2 and Ar3 had been chiefly made were: firstly, a sample of Swedish bar-iron, brand DU, containing 99·8 per cent. of iron; and secondly, as it was felt advisable also to examine iron which had been fused, in order to get rid of any contained cinder, a fifty-pound ingot of fused wrought-iron was made in a special crucible by the aluminium process suggested to the Sheffield Metallurgical Society two years ago. This material, which hammered and rolled exceedingly well, gave remarkable chemical and mechanical tests. Its composition was as follows: carbon 0·07 per cent., silicon 0·04, manganese 0·06, phosphorus 0·02, sulphur 0·02, aluminium 0·03, and iron 99·76 per cent. The mechanical test on a test piece of $\frac{1}{4}$ square inch area and 2 inches length was in round numbers a maximum stress of 21 tons per square inch, with 50 per cent. elongation, and 80 per cent. reduction of area. In the cooling of both these materials the evolution of heat at the lowest or carbon change-point Ar1 was so small as to be barely perceptible: the other two points however were well marked. It was next noticed that, although, as already pointed out by M. Osmond, the point Ar3, and to some extent also the carbon change-point Ar1, was lowered during cooling from a high initial temperature, the point Ar2 was practically unaffected by this condition: in other words, the lower and upper points Ar1 and Ar3 possessed similar properties both in respect to the temperatures at which they occurred during cooling and during heating, and also in regard to the influence of a high initial temperature; whilst the temperature at which the intermediate point Ar2 appeared was almost uninfluenced by any of these same conditions, the point Ar2 being thus peculiar in these respects. Formerly in his own opinion the upper critical point Ar3 marked not necessarily an allotropic change, but one from a plastic to a crystalline condition, or *vice versâ*.* M. Osmond on the contrary was of opinion that none of the three points had anything whatever to do with crystallization, which he considered to occur above 900° C. or 1,650° Fahr.; and although he admitted the principle that crystallization should be accompanied by a slight evolution of heat, yet neither his curves nor those of Professor Roberts-Austen indicated the slightest perturbation at the above temperature. The remarkable constancy of the intermediate point Ar2, in regard to the temperature at which it appeared, had led himself to the conclusion that it must indicate a true physical change, rather than one due to the chemical dissociation or combination to which the lower point Ar1 was known to be due. A series of experiments had therefore been made in order to determine the temperature at which iron passed from the crystalline to the plastic condition. These determinations had been made in the following manner. Bars of the two kinds of iron already described —Swedish bar iron and fused wrought-iron—were rolled out at a low red heat, in order to produce a well-marked elongation of the crystals present in the original bars. When cold the rolled bars revealed under the microscope the fact that the crystalline grains had been drawn out into fibrous strings. Pieces of the bars were then heated in connection with the thermo-couple to various temperatures between 650° and 950° C., or 1,200° and 1,740° Fahr. Sections from the various trial pieces being then polished, etched, and microscopically examined, it was found that the iron had changed from a fibrous to a granular condition at about the point Ar2. Pieces heated up only to the temperature of the lower point Ar1 showed the

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* See "Engineering," 1891, Nov. 13, page 575; and 1892, March 11, page 331.

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fibrous structure but little modified; at the intermediate point Ar2 the structure consisted of small grains; and at the upper point Ar3 the large normal crystals were entirely re-formed, indicating that the metal had been re-heated to a temperature considerably above its crystalline change-point, or, in other words, that iron crystallized at a temperature approximating to 750° C. or 1,380° Fahr.

There now remained only the upper point Ar3 to consider. The fact that its property so closely resembled that of the lower point Ar1, which was known to be of chemical origin, led to the reasonable supposition that Ar3 also was due to a chemical cause; and it became necessary to speculate as to the element producing it. From certain data which he had obtained, he would suggest as a tentative hypothesis for enquiry the possible influence of the element hydrogen. Both M. Osmond and Professor Roberts-Austen had assumed that any possible influence of this element upon their thermal indications had been guarded against by merely heating to a red heat the samples of iron dealt with. Such an assumption however seemed remarkable in face of the fact that twelve years ago it had been pointed out by Mr. Parry that, even after iron had been maintained for a week at about 1,000° C. or 1,800° Fahr. in a partial vacuum, it still continued to give off hydrogen (Journal of the Iron and Steel Institute, 1881, part 1, page 189).

Professor ROBERTS-AUSTEN drew attention to the experiment he had described in the former discussion (Proceedings 1891, page 570, and Fig. 17, Plate 122), in which a piece of electro-deposited iron had been heated red hot in a vacuum; and he remembered having carefully observed that every trace of occluded gas had thereby been driven off.

Professor ARNOLD regretted that he had overlooked that experiment; he thought M. Osmond had stated that a red heat was itself sufficient to exclude hydrogen. In describing the experiment just referred to, it had been stated by Professor Roberts-Austen that the evolution of hydrogen ceased before the iron reached a temperature of 400° C. or 750° Fahr., that is at about a black heat. The result obtained was also abnormal, inasmuch as the intermediate point Ar2 was absent, and the higher point Ar3 appeared at the same temperature of 850° C. or 1,560° Fahr. both in heating and in cooling. Remarkable microscopic indications having been obtained that the iron under examination in his own researches contained large quantities of highly compressed gas, one of the recalescence pieces was maintained at a white heat for seventeen hours in a vacuum varying from 24 to 29 inches of mercury. Analyses made at intervals of the extracted gases showed during the early hours of the experiment the presence of carbonic acid, carbonic oxide, nitrogen, and hydrogen; but during the sixteenth and seventeenth hours the unexhausted steel was evolving practically pure hydrogen. A recalescence test was then made upon the piece. The chronographic curve indicated that the highest critical point Ar3 had been distinctly affected, not in the direction of obliteration, but the change occurred much more sharply between narrower limits of temperature. This fact might possibly be interesting in connection with Professor Roberts-Austen's observations on the influence of internal pressure upon recalescence. The problem now necessary to be solved in connection with the point Ar3 was, whether the occurrence of this point was due to a combination of hydrogen dissolved in the iron to form a hydride, by a reaction analogous to that at the lower point Ar1, where the dissolved carbon formed a carbide. In conclusion he could only reiterate his conviction, with which the practical experience of Mr. Hadfield led him to agree, that the profoundly different physical conditions capable of being assumed by steel had little connection with any allotropic modification of iron itself, but were due almost entirely to the action of carbon. It might be laid down as an axiom he considered in steel metallurgy that, if care were taken of the crystals, the molecules would take care of themselves; and he maintained that, as the blood was the life, so was the carbon the steel.

Mr. ROBERT A. HADFIELD, as a member of the Alloys Research Committee, had read Professor Roberts-Austen's second report with much interest. Having at the last meeting of the Committee had the pleasure of hearing an account of his interesting and exhaustive work, as well as of seeing proofs of his numerous experiments in connection with this question, he must, whilst not agreeing with some of the conclusions drawn, heartily congratulate him upon this work. He had indeed placed before this Institution a highly valuable collection of facts, which would without doubt have considerable bearing upon future developments in metallurgical practice. It was a matter of much regret to himself that he was unable to agree with the interesting theory of β or hard iron; and he felt, with Professor Arnold, the need of great caution in advancing a theory of that kind without adequate proof. It was already tending to spread, he found, in connection with technical school education; and he had more than once met with students who had been taught that the hardening of steel could be explained as due to the iron having assumed the β or hard form. At present there was not sufficient evidence, he thought, to warrant that conclusion. Apart from carbon, the other elements useful to be alloyed with iron—namely manganese, chromium, tungsten, nickel, cobalt, and copper—when added in small quantities, say less than 0·2 per cent., appeared to influence iron but little comparatively, at any rate as regarded its mechanical properties, such as tensile strength, ductility, and point of permanent set, all of which varied but little. To these elements might also be added silicon and aluminium, secondary elements of no special value either as additions in themselves or as materially altering the physical qualities of iron, but used with other objects in view. In other words, as regarded the influences of small traces of added elements upon iron, it seemed to him that iron alloys containing one-tenth per cent. of any one of the above elements, but free from carbon, would differ but slightly from one another, and but little from an iron alloy containing one-tenth per cent. of carbon. Having been quite unaware of what Professor Arnold was going to say, he had been glad to hear the particulars of the experiments he had made with fused wrought-iron. There was an excellent steel-furnace in connection with the Sheffield Technical School; and he considered it did Professor Arnold great credit to have produced the melted sample of wrought-iron which he had afterwards been able to forge and test in the way described. As far as his own experience went, it was an exceedingly difficult matter to prepare an ingot of pure iron, or a satisfactory ingot from which test-bars could be made. As was well known, the melting of such material—that is, carbonless iron—took place only at exceedingly high temperatures. When no other elements were present, there was considerable liability for it to take up gases. Therefore to obtain a satisfactory test-bar from such a material was not easy. It was only on largely increasing the percentages of the added elements that the special quality of each individual alloy began to show itself. Iron alloyed with manganese, for example, had several distinct grades or stages, say first up to 1½ per cent. of manganese, then from 1½ up to 7 per cent., next from 7 up to 14 per cent., and finally from 14 to 20 per cent., at which highest proportion it ceased to be a malleable alloy. For this reason it could not be said that in alloys of iron there was any one definite percentage to be considered of the added ingredient; and this was a point which he should like to be strongly emphasized in the work of the Alloys Research Committee. Nickel and cobalt did not produce any such distinct grades of alloy, so far as his observations enabled him to judge; and they certainly did not show the peculiarities of manganese steel. To the theory that elements whose atomic volume was smaller than that of iron (7·2) produced a hardening effect upon iron, a remarkable exception was presented by nickel (6·7 atomic volume); carbonless nickel-steel, varying from 0·1 up to 10 per cent. of nickel, did not show when subjected to water-quenching any signs of change in molecular structure, or of hardness resembling that of water-quenched carbon-steel, not even when the nickel-steel was water-quenched from temperatures as high as from 1,800° to 2,000° Fahr. All the samples that he had tested in this way had been quite soft after such treatment, and easily filed. The effects of additions of chromium and tungsten somewhat resembled each other, although these elements varied considerably in their atomic volumes, 7·7

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and 9·6 respectively. These again had a somewhat different set of properties from those produced by manganese. Tungsten was probably the stronger of the two as regarded its influence in stiffening iron, when added in comparatively large amounts. Copper (7·1 atomic volume) stood apart from chromium and tungsten, giving a sort of superior silicon (11·2) and aluminium (10·6) steel. The malleability of a copper alloy ceased at about 3 to 3½ per cent., whereas silicon and aluminium might be allowed to go about 1 per cent. higher before the steel ceased to be malleable. When speaking previously on the subject of iron alloyed with copper (Proceedings 1891, page 579), he had been under the impression, as far as his experience had then gone, that a comparatively small amount of copper added to iron would render it incapable of being forged; and he was afraid he had done Professor Roberts-Austen wrong on that occasion, because from later experiments he now quite agreed that an alloy of iron with 3 per cent. of copper could be got which was malleable. This experience accordingly confirmed strongly what he considered when completely established must constitute a highly valuable feature of the present research, namely the ability to judge the effect of elements added to iron by their respective atomic volumes. In this part of the work therefore he heartily agreed as to the great value of the results obtained by Professor Roberts-Austen. From the results obtained in his own experiments it had certainly seemed to him difficult indeed to define the precise effects produced on the mechanical properties of iron in the testing machine by alloys of small amounts of added elements. Three tungsten experiments which he had recently made would probably be of interest, as the atomic volume of this element was 9·6, but little lower than aluminium 10·6, and much higher than iron 7·2. With a thin sample containing 1½ per cent. of tungsten and about 0·2 per cent. of carbon, quenched rapidly, he had been able to scratch glass. But notwithstanding this, he thought that tungsten had similar effects to chromium; and if this was so, inasmuch as both chromium and tungsten had atomic weights above that of iron, tungsten should therefore, according to the theory advanced in the first report, tend to soften iron. It was here that he regretted being unable to agree with Professor Roberts-Austen. The following were the results of the three tests:—

Iron alloyed with Carbon and Tungsten.		Sample 1.	Sample 2.	Sample 3.
Carbon	per cent.	0·13	0·13	0·21
Tungsten	per cent.	0·10	0·38	1·49
Elastic limit per square inch .	tons	14½	16½	19½
Tensile strength per square inch .	tons	22½	23	28½
Elongation . . .	per cent.	43·10	44·95	36·90
Reduction of area . .	per cent.	65·46	68·90	54·80

The first two samples gave only 22½ and 23 tons tensile strength, a high elongation and a low elastic limit, thus clearly showing that tungsten did not cause increased stiffness of iron. If the use of the atomic-volume table (Proceedings 1891, page 544) was to indicate the prejudicial or beneficial effect of an element added to iron according as its atomic volume was greater or less than that of iron, he believed practical metallurgists would find Professor Roberts-Austen's research work of considerable service; but when the theory was advanced that those elements whose atomic volume was below that of iron produced a hard condition of iron, and those having a higher atomic volume a soft condition of iron, he must express his own strong dissent from this view. All the alloy work yet undertaken seemed to him to prove clearly that there was one element alone, namely carbon, which in combination with iron produced its hard condition; and that it was necessary to look to other facts for an explanation of this phenomenon. In relation to this fact the following hypothesis, which accorded with his own views and was based upon molecular change, had been aptly propounded by Professor John W. Langley in a recent discussion on structural steel at the American Society of Civil Engineers (October 1892, page 405):—"The solution of carbon in steel above the recalescence point is practically perfect, unless the dose of carbon is very large. At the recalescence point and below it, the excess of carbon tends to crystallize out; hence very rapid cooling of the steel is necessary to retain it in solution. Also the formation of large crystals is prevented, only small ones being produced and forming the refined grain." And the words then immediately following seemed to him

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to sum up the most satisfactory explanation of the hardening of steel:—"This disturbance of the crystalline forces results in violent molecular stresses which produce hardness." As far as his own experience went, this was to a great extent a satisfactory explanation of the phenomena noticed in hardening. In corroboration Professor Langley went on to cite the familiar fact that "cold rolling or hammering of any metal whatever hardens it. The function of the carbon is so to alter the ordinary molecular aggregation of iron that this strained grouping can be brought about within easily managed limits of temperature." These remarks appeared to him highly valuable, and summed up better than he could himself a satisfactory explanation of the phenomenon of hardening.

The discussion was adjourned at this point on Thursday evening, and was resumed on Friday evening after the reading of Mr. Dean's Paper on "Tensile Tests and Chemical Analyses of Copper Plates from Fire-boxes of Locomotives on the Great Western Railway" (pages 139–144).

The President regretted that Mr. Dean could not be present; but he was certain that the members would agree in passing a vote of thanks to him for his paper. Although it had taken so few minutes to read, it contained a large amount of practical information, which he was sure would ultimately prove of great advantage in connection with Professor Roberts-Austen's researches on the influence of small quantities of impurity upon the physical properties of metals.

Mr. Bertram Blount considered Professor Roberts-Austen's report was so full of excellent matter that, especially after witnessing the fascinating experiments he had shown, a reasonable diffidence might be felt in commenting on one or two points which were perhaps of minor importance, but upon which he would venture to touch with the view of gaining further information. In page 112 a description was given of the method adopted for taking the temperature of heated specimens of copper rods, tested for tensile strength, and broken while being heated. The plan employed would naturally suggest itself to one who had used the thermo-electric pyrometer with such remarkable success; it consisted in tying the junction to the specimen, and observing the autographic record obtained from the current generated by the junction. Having himself had some little experience in breaking by tension specimens of metals and alloys at temperatures above the ordinary, and not being so perfectly equipped with such admirable appliances as those employed by Professor Roberts-Austen, he had had to fall back upon humbler means. Those that he had used, though perhaps not quite unexceptionable, were sufficiently delicate to show that there was a considerable difference between the temperature at the middle and that at the ends of the specimen, no matter how careful and regular was the heating of the air-bath he had adopted, which was practically identical with that described in page 112. It seemed to him that the ends of the specimen were considerably cooler than the middle, sometimes many degrees cooler; and he ascribed the difference of temperature to the fact that the heat streamed away at each end by contact of the specimen with the heavy clips of the testing machine; and unless it was possible to use clips of some non-conducting material, he scarcely saw how that was to be avoided. The question thence arising was whether in Professor Roberts-Austen's tests the temperature had been taken at the middle or at the ends of the specimens, or at various points. If the latter, had it been found to be identical at all points? and if not identical, and the different temperatures had previously been plotted for the several points observed on the specimen, was the recorded temperature at which it broke that proper to the particular point at which the fracture actually occurred? If the observations recorded in Table 1 in the report were in any way coincident with his own, there would be a perceptible difference between the temperatures at the middle and at the ends.

The tenacity of pure copper was given in page 119 as 9·38 tons per square inch at 570° Fahr., on the authority of M. André Le Chatelier; while that of arsenical copper at the same temperature, according to the experiments recorded in the report, was considerably higher, namely 12·6 tons. Having constantly to analyze specimens

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of copper for locomotive fire-boxes, he knew that the users of copper for that purpose had strongly objected to arsenic; and he was therefore pleased to see that Professor Roberts-Austen's results confirmed the conclusion already arrived at by Professor Hampe (page 120), that the arsenic was much less mischievous than had at one time been supposed: thus exonerating the older locomotive makers, who considered that arsenic was rather good for copper, and that those who objected to the presence of 0·5 per cent. made a mistake in doing so. Although therefore 0·15 per cent. of arsenic in copper was the maximum favoured by engineers at the present time, he thought they should be chary in condemning copper because it contained more than this regulation amount. A point of particular interest in these mechanical tests recorded in Table 1, which appeared to have been carried out with much fairness, was that more data were here given than in those that could be quoted from foreign observers. In page 120, for example, the influences of arsenic and antimony upon copper, as observed by Hampe, were detailed; and mention was made of the fact, which had previously attracted his own attention, that Hampe had not attempted to ascertain the strength of these alloys at temperatures higher than that of the atmosphere; nor, it might be added, had he given their elastic limit, or anything but their tensile strength at atmospheric temperature. Clearly that was a gap which had been well filled by a number of the experiments recorded in Table 1. In the absence of facts of this kind, engineers might perhaps have been content to say that the addition of arsenic to copper made a hard metal or a strong metal; but whether it made a safe metal was not previously known. From Professor Roberts-Austen's work it appeared to him that, although it was still hard to say definitely that it made a safe metal, there was at least good reason now to hesitate before condemning it off-hand.

The observations as to the influence of bismuth on copper (pages 120–3) were most interesting. Analysts had already been in the habit of searching for bismuth in copper and copper alloys, and he believed its presence was strongly objected to by makers of certain copper alloys; but now that it was seen what a minute portion caused such marked effects, and now that the cause of those effects was understood, the search for bismuth would be even keener than before. By means of the method given in the appendix to the report (page 138), he had no doubt that powerful aid would be afforded for the detection of quantities still more minute.

Another point which appeared to him to be of great importance and interest was the statement in page 124 that the presence of small quantities of foreign elements, such as aluminium or nickel, increased the endurance of the metal by rendering it less ductile. Nickel was one of the elements frequently found in copper, notwithstanding that its presence was so often ignored in ordinary analyses. Having himself nearly always found nickel in commercial copper, he was glad to believe that his own experience in this particular was borne out both by the analysis in the appendix (page 138) and by the experience of one so eminent in the metallurgical world as Mr. Edward Riley, in whose analyses of copper he believed nickel usually appeared. The gist of the matter was: if aluminium or nickel produced a special and beneficial effect on copper, might it not be possible that an alloy could be produced as much superior to copper as was already aluminium-bronze?—taking the latter as an example of an alloy containing a fair quantity of foreign metal. It was quite conceivable however that a small quantity of a foreign element might change the quality of copper in a marked degree, as the addition of a small quantity of carbon changed the quality of iron.

The use of the electric furnace in the laboratory appeared from the experiments of M. Moissan (Comptes Rendus, vol. cxv. 1892, pages 1031 and 1034, and vol. cxvi. 1893, page 549) to be a most valuable innovation; and he had no doubt that it would be applied by the Research Committee with good effect. There were many others besides himself, he was sure, who felt greatly indebted to Professor Roberts-Austen for the highly valuable information he had given them in his reports to the Research Committee.

The President asked if Mr. Blount had used the spectroscope in his search for impurities in copper.

Mr. Blount replied that the quantities in ordinary copper were not so minute as to need the aid of the spectroscope for their detection.

Dr. David Watson, Manager of the works of the Broughton Copper Co., Manchester, noticed that Professor Roberts-Austen had very properly drawn a distinction between copper which contained a proportion of oxygen as a constituent, and that which did not; and had in the main confined his observations to the latter. It had been his own fortune to work a good deal with copper in both these categories; and he would therefore say what was his experience on some of the points touched upon in the present report. With pure copper free from oxygen he was familiar in two forms: firstly in the condition in which it was deposited from solution by the galvanic current, that is, electro-deposited; and secondly after fusion. By observing certain precautions, copper might be electro-deposited in a condition perfectly comparable with that of ordinary wrought copper. The production of such copper was part of the regular business of the Broughton Copper Co., and he had tested many pieces of copper of that character to ascertain its adaptability as a material for mechanical engineers. As was pointed out in the report (page 110), certain precautions were necessary to prevent the formation of oxide when copper was melted for casting. Whilst he could not but admire the ingenuity with which Professor Roberts-Austen had managed to do this in the preparation of his experimental rods, he himself preferred the method which was employed by those copper manufacturers who produced articles of de-oxidized copper: namely the addition to the fused copper of a regulated quantity of phosphorus, slightly in excess of the quantity required to de-oxidize the copper; the slight excess prevented the formation of oxide in pouring. The action of the phosphorus on the molten metal was immediate and complete: all the oxygen was removed in the phosphatic slag which was formed, and which separated from the molten copper like oil from water. Electro-deposited copper prepared with proper precaution, and without any mechanical work put upon it at any stage, was in what would be readily understood as the half-hard condition. In one series of tests he had prepared and dealt with copper which, as deposited, broke at a tensile strain of 16 tons per square inch with an elongation of 20 per cent.; the same copper annealed gave 13·6 tons (30,464 lbs.) tensile strength, and 42 per cent. elongation: this he should take provisionally as representing pure copper. The elongation was measured in a length of 4 inches, and the test piece was 1 inch wide and 0·106 inch thick. Both in tensile strength and in elongation, as well as in other respects, this copper was inferior to good commercial copper of the oxidized kind. It would probably not be impossible, though difficult, to deposit electrically copper containing definite minute quantities of other metals; and the study of a series prepared in that way would doubtless throw further light on the difficult subjects dealt with in the report. The tensile strength of 30,464 lbs. per square inch and elongation of 42 per cent., which he had obtained for pure copper, agreed closely with those given in Table 1, test No. 22, namely 30,170 lbs. and 37 per cent.; but differed greatly from Nos. 13, 14, 20, 37, and 38. Whilst recognizing the great interest attaching to the experiments reported, it appeared to him from a survey of the results that, in some cases at any rate, the method of casting employed had failed to secure the object aimed at, namely perfectly sound castings free from defects; and that the mechanical work put on the cast rods in preparing the wrought specimens had not been sufficient to obliterate the defects existing in the castings.

A good many years ago he had himself made in the course of business a limited series of experiments similar to those of Professor Roberts-Austen, to determine the effect of certain impurities on the tensile properties of copper at ordinary temperatures; the experiments were made not for publication, but in order to test the method by which the copper was manufactured. The copper was electrotype copper, melted and de-oxidized by phosphorus as previously described. Each casting was of 6 lbs. of copper, and the quantity of phosphorus added in each case was the same, namely 2-10,000ths or 0·02 per cent.; the phosphorus was added as copper phosphide. The metal after de-oxidation was cast into strips 6 inches long, 7-8ths inch thick, and 2 inches wide; these were rolled cold down to $\frac{1}{4}$ inch thickness without annealing. Their mechanical properties must therefore have been good, as they stood the severe rolling so well. From the resultant rolled metal the test pieces were cut, and carefully annealed before testing. The following were the results of nine experiments, illustrating the influence of arsenic, antimony and lead:—

		Tensile Strength per square inch.	Elongation in 2 inches.
Pure Copper		14·38 tons	62·5 per cent.
Arsenic	0·050 per cent.	14·29 ,,	60·0 ,, ,,
	0·111 ,, ,,	14·39 ,,	61·0 ,, ,,
	0·188 ,, ,,	14·39 ,,	61·0 ,, ,,
Antimony	0·025 ,, ,,	14·50 ,,	56·5 ,, ,,
	0·100 ,, ,,	14·58 ,,	58·5 ,, ,,
	0·200 ,, ,,	14·77 ,,	60·0 ,, ,,
Lead	0·050 ,, ,,	14·21 ,,	62·5 ,, ,,
	0·200 ,, ,,	14·36 ,,	58·0 ,, ,,

These figures did not entirely agree with Professor Roberts-Austen's, with which therefore he would not attempt to compare them, having already referred to the irregularity of the results in Table 1 and to one of the causes of that irregularity. If his own figures here given were accepted, it would be seen that, at the ordinary temperature and within the limits given of percentage, arsenic did not affect the tensile strength and scarcely the elongation of de-oxidized copper; antimony slightly improved the tensile strength, but lowered the elongation; lead slightly lowered both the tenacity and the elongation.

With regard to bismuth, he had no figures to compare with Professor Roberts-Austen's, but must express the extreme interest with which he had read the record of experiments Nos. 6 to 11 in Table 1, and the most successful pyrometric demonstration (page 122) of the cause of the phenomena observed. A highly interesting fact, to which he wished to draw attention, was that in de-oxidized copper lead behaved in a manner precisely analogous to that in which bismuth behaved, rendering the copper perfectly rotten at elevated temperatures.

One of the most important points studied by Professor Roberts-Austen was the change in properties of copper as the temperature increased. This was becoming a more and more important consideration for engineers, owing to the high pressures of steam now so generally employed, and the corresponding high temperatures to which copper steam-fittings were raised in actual service. Ordinary oxidized copper was much superior to de-oxidized copper in this respect. The influence of impurities on copper, in the oxidized condition in which it was ordinarily used by engineers, was in some cases different from their influence when the copper was de-oxidized. Almost all the wrought copper in the world contained lead, and at some stage of its manufacture had been worked at a red heat. Copper containing even only so minute a proportion of lead as 0·05 per cent. or less was quite incapable, if de-oxidized, of being worked hot. If his own experiments were to be relied upon, it had already been seen that arsenic did not increase the tensile strength of de-oxidized copper, but it added to that of oxidized. Antimony was rarely present in sufficient quantity to influence the properties of wrought copper materially, but its tendency was to cause cold-shortness. Bismuth, unlike lead, behaved towards oxidized copper in precisely the same way as towards de-oxidized; copper containing even a very small percentage of bismuth displayed the hot-rottenness demonstrated by Professor Roberts-Austen. There was much more difficulty in tracing the effect of metallic impurities on the properties of oxidized than of de-oxidized copper. The proportion of oxygen, which varied more or less within certain limits, affected the physical properties of copper seriously: generally much more seriously than the presence of more or less of the impurities of which he had previously been speaking. The whole question of the proportion of oxygen which ought to be present in order to confer the best properties on copper containing various impurities had hitherto not been at all successfully investigated, as far as he knew. It was a subject presenting a really bewildering perplexity, and involving difficult chemical analyses. Published analyses were usually quite wrong in the figures given for oxygen; the point was apparently treated by analysts as a matter of small moment, and in the whole of

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the analyses given in Mr. Dean's paper (page 143) as well as in that given by Professor Roberts-Austen (page 138) he believed the amount of oxygen stated must be much less than that actually contained in the specimens analysed. The margin to be allowed as regarded the percentage of oxide varied undoubtedly with the percentages present of certain metals other than copper; and therein lay the reason for the use of lead, which was regularly added to copper in refining, because its presence in the molten metal allowed the refiner a useful latitude. Arsenical copper required no such addition, because the margin of allowance for oxygen was doubtless provided by the influence of the arsenic.

Much experience and many comparisons of analyses with tensile and other tests showed that the most satisfactory copper for the ordinary purposes of mechanical engineering contained arsenic from 0·35 per cent. upwards. The practice at the Broughton Copper Works was to make the upper limit about 0·5 per cent.; but copper containing more than this percentage might still be of excellent quality. Such copper should be so refined as to contain also an amount of oxygen between certain limits; this was left to the skill of the refiner, whose success must be judged by the results obtained. The composition of the mass of molten copper put into the refining furnace was perfectly known in regard to every other ingredient, except the amount of oxygen; and when the copper came under the refiner's care, it contained a considerable excess of oxygen, or was at least saturated with it. The refiner's business was to remove the excess of oxygen, and, if he had removed too much, to add some more: until judging by the properties of the copper he found it was what was called "in pitch," which meant that he had got a sufficient amount of oxide or of oxygen present in the copper to bring it to a good tough quality. The means he had at his disposal were, first of all, means for oxidizing the copper by the air, either by admitting air or by blowing it in, or by other methods; and next, means for de-oxidizing it, either by covering the surface of the metal with carbon, or by the old practice of "poling" or stirring the metal with a pole of wood, from which the reducing gases in passing through the metal de-oxidized it; there were also other ways of effecting the de-oxidation.

On Mr. Dean's paper he was unable to offer any criticism in detail, inasmuch as there seemed to him a want of agreement between the electrical conductivity found and the composition of the metal as shown by the analyses given. From the laboratory books of the Broughton Copper Works he had extracted a few particulars, which indeed were not conclusive in themselves independently, but still agreed on the whole with the conclusions to be drawn from Mr. Dean's paper. Although copper plates were not made at the Broughton Works, yet copper fire-box plates that had failed in locomotives had frequently been sent there for examination as to the cause of failure. The very first samples so received were the results of the scientific curiosity of a locomotive engineer, who wanted to have pretty much the same tests made that Mr. Dean had now been carrying out. Some years ago three samples of copper were received, which had been taken from three locomotive fire-boxes of similar construction that had been working under similar conditions, but with very different results: No. 1 failed after two years, No. 2 after nine years, and No. 3 after twenty years. About the respective mileages and other conditions of working, no information was received. The following were the results of the analyses made:—

No. 1	Lead	0·322	per cent.	Arsenic	0·192 per cent.
No. 2	,,	0·226	,, ,,	,,	0·142 ,, ,,
No. 3	,,	0·079	,, ,,	,,	0·847 ,, ,,

The next examples were two specimens of copper plate, Nos. 4 and 5, of which No. 4 was a quality much preferred to No. 5 on account of its giving no trouble to the locomotive builders in working it either hot or cold; but both alike were representatives of large numbers of fire-box plates that had been made and had formerly received approbation, though No. 5 had subsequently been discarded as not so good to work. Their analyses showed the following considerable differences:—

No. 4	Lead	0·025	per cent.	Arsenic	0·449 per cent.
No. 5	,,	0·124	,, ,,	,,	0·019 ,, ,,

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The next sample, No. 6, was received from the locomotive engineer of one of the largest railways, as a portion of one of the best fire-boxes he had ever known, which had been at work for many years; the locomotive he believed had been made and the fire-box put in as long ago as 1847, and it was now not more than ten years since the sample was taken out and analyzed with the following results:—

No. 6	Lead	0·136 per cent.	Arsenic	0·332 per cent.

The following were analyses of five plates that had failed prematurely. No. 7 was a tube-plate which had been broken between the tubes by the alternate expansion and contraction of the tubes in heating and cooling; they were longer tubes than usual, and were consequently subjected to rather more action of that sort than ordinarily took place, and the action went on until the plate broke right through. Nos. 8, 9, 10, and 11 were crown-plates, which failed by longitudinal cracks.

No. 7	Lead	0·384 per cent.	Arsenic	0·065 per cent.
No. 8	„	0·194 „ „	„	0·047 „ „
No. 9	„	0·214 „ „	„	0·046 „ „
No. 10	„	0·164 „ „	„	0·053 „ „
No. 11	„	0·215 „ „	„	0·047 „ „

Putting the above figures together, three analyses were of plates which had earned an exceptionally good character, whilst eight were of plates that had stood badly.

Three good plates.

	Lead.	Arsenic.
No. 3	0·079	0·847
No. 4	0·025	0·440
No. 6	0·136	0·332
Average	0·080	0·540

Eight bad plates.

	Lead.	Arsenic.
No. 1	0·322	0·192
No. 2	0·226	0·142
No. 5	0·124	0·049
No. 7	0·384	0·065
No. 8	0·194	0·047
No. 9	0·214	0·046
No. 10	0·164	0·053
No. 11	0·215	0·047
Average	0·230	0·080

Comparing these two groups, it appeared that the best plates were those containing a fair percentage of arsenic and but little lead: a conclusion to which the general experience of copper at the Broughton Works would also lead.

Mr. William Gowland, of the Broughton Copper Co.'s Ditton Works, Widnes, said that, amongst the important results of the researches made by Professor Roberts-Austen and contained in his present report, there was one which appeared to himself to be a most noteworthy discovery: namely the second or lower break in the cooling curves of copper-bismuth alloys, shown in Fig. 19, Plate 32. By no other method known to himself could such light be thrown on the state in which some of the bismuth existed, and on the manner in which it acted in producing brittleness in such alloys. Some years ago he had made a long series of experiments in the Imperial Mint, Japan, upon the effect of the presence of bismuth on silver, the ingots of silver being found too brittle to roll into bars for coining; and the particulars of the experiments had been published in the Proceedings of the Chemical Society (1887, vol. 51, page 410). By making a number of synthetical alloys he had found that the effect of bismuth when added to pure silver was that it produced the most extraordinary brittleness: so much so that an ingot weighing 1,000 ounces, and measuring in cross section about four inches square, was broken easily by a blow of a hammer; in fact so brittle was it that, in cutting a small assay piece from it, the ingot broke into two pieces. The fracture being coarsely crystalline, he succeeded in detaching several crystals, and to his surprise the crystalline granules possessed the most perfect malleability and ductility. The curious thing was that the mass broke up when it was subjected to the mechanical treatment of hammering or rolling; yet the individual grains of which it was built up possessed the utmost ductility. Chemical analysis failed altogether to show the cause of this peculiar behaviour. Until reading the present report (page 122), where the discovery of the lower break in the bismuth curve was announced and its explanation given, he had been unable to account satisfactorily for this peculiar behaviour of the silver-bismuth alloy. Thanks however to these able researches by Professor Roberts-Austen, it was now clear that the silver-bismuth ingot consisted of crystals or crystalline grains of the alloy, separated from one another by an infinitesimally small film of what, chemically speaking, might be called a "mother liquor," which consisted of the metal bismuth.

(Mr. William Gowland.)

Another highly important point brought to light in this report was that which related to the diminution in strength of copper-bismuth alloys at higher temperatures. In tests 6–11 of Table 1 (page 114) the tenacity of copper containing 0·1 per cent. of bismuth was given as 18,020 lbs. per square inch at the ordinary temperature, while at 214° Fahr. it was only 11,510 lbs., and at 558° it was reduced to as low as 2,770 lbs. The effect of bismuth in lowering to such a great extent the tenacity of copper had, so far as he was aware, been demonstrated now for the first time, and was a surprise to most metallurgists, to whom the brittleness induced by bismuth in copper had long been known; but this great lowering of tenacity when the temperature was raised had not been known or suspected. The knowledge of this effect of bismuth would be of the utmost value to those engineers who had to use copper in positions in which it was liable to be exposed to such temperatures. Copper contaminated with bismuth was evidently unsuitable for bolts, rods, or tubes, which might by any chance be heated to such temperatures. Metallurgists generally, he was sure, would join with himself in thanking Professor Roberts-Austen for the valuable addition he had made to their knowledge of the influence of foreign metals upon copper; and all hoped that he would extend his researches further, especially into the effects of bismuth upon copper.

In reference to the locomotive fire-box plates forming the subject of Mr. Dean's paper, he could not at all understand the relation between the electrical conductivity and the chemical composition. Sample No. 1, for instance, was from a fire-box plate containing 99·486 per cent. of pure copper (page 143), and yet the electrical conductivity was stated to be only 67·2 per cent. (page 144). Again, No. 4 contained no less than 99·828 per cent. of copper, and yet its electrical conductivity was given as only 69·95 per cent. Another result, No. 11, was 99·750 per cent. copper with 63·01 per cent. conductivity; and No. 12 was 99·630 per cent. copper with 65·66 per cent. conductivity. The last, No. 18, was 99·810 per cent. copper with 78·1 per cent. conductivity. These conductivities would indicate almost certainly that the plates contained considerable quantities of arsenic. Certainly No. 11 with only 63·01 conductivity must have contained not less than 0·20 or 0·25 per cent. of arsenic: that is, if the copper was tough, and contained no excess of oxide of copper. If it had contained an excess of oxide of copper, it would have been impossible to make it into a fire-box plate. Yet the electrical conductivity he considered must be assumed to be correctly ascertained, because there was no difficulty whatever in determining it with the utmost accuracy. On the other hand, what was to be said of the chemical analyses? Certainly he was not prepared to say that they were wrong. Still it seemed impossible to account for the low electrical conductivity from the analysis given, because the particular samples to which such low conductivities were assigned ought unquestionably from their analyses to have an electrical conductivity of at least from 95 to 98 or 99 per cent., whereas the highest given was only 78·1 per cent. In sample No. 5 indeed the low conductivity of 22·28 per cent. was somewhere about what it should be for copper containing so much as 0·811 per cent. of arsenic; but in all the purer samples there seemed to him to be something decidedly wrong. For supposing that the chemical analysis was right and that the electrical conductivity was also right, the copper must have undergone some unknown change while it had been in the fire-box of the locomotive, of which he thought no account could be given. The only cause which had occurred to him of such a change would be the presence of oxide of copper; but he could not understand an amount of oxygen entering into a copper fire-box plate sufficient to reduce its electrical conductivity to the low percentages that had been given; and to himself these anomalous results remained inexplicable.

Mr. Henry C. Jenkins, referring to Dr. Watson's experiments on the presence of lead in copper (page 170), thought that various interesting questions were raised by the fact that two metals, possessing quite different properties, could in many cases retain their individuality side by side in an apparently homogeneous alloy. In connection with the experiments carried out for the present research, attempts had been made to get small percentages of lead into copper for testing in the form of the copper rods described

(Mr. Henry C. Jenkins.)

in pages 111–112; but so far the endeavour had been unsuccessful. Was Dr. Watson perfectly sure that oxygen was absent from the copper in which the lead was present? Even after the two metals had been melted well together and shaken, they could not be made to mix; when cast in the carbon tubes (page 111) they separated, and the lead was found in the upper part of the tube, on the top of the copper. The behaviour of the lead towards the copper in the absence of oxygen appeared to be similar to that of bismuth, only much exaggerated. When the bismuth and copper were melted together for any one of the intermediate alloys illustrated in Fig. 19, Plate 32, and then allowed to cool at a moderately rapid rate—perhaps a mass of ½ lb. cooling in a quarter of an hour—there was not so much separation to be seen. But if the cooling were prolonged for five or six hours, so that a considerable interval of time elapsed between the initial freezing of the copper and the freezing of the residue, separation took place to such an extent that the copper was found in the form of individual crystalline grains in the midst of a white metallic mass, which no doubt was bismuth. Lead with copper seemed to present such an exaggerated example of the same phenomenon, which much resembled that of aqueous solutions, that perhaps the experiments attempted could not be performed rapidly enough to keep the two metals mixed.

Dr. Watson pointed out that the experiments he had made (page 170) had been with such small quantities of lead, only 0·05 and 0·20 per cent., that it was not so easy for the lead to separate itself from the copper, however slowly the cooling took place.

Professor T. Hudson Beare said that in his experiments referred to in page 124 of the report he had drawn attention to one point of importance in regard to copper and its alloys, namely the difficulty of determining what was commonly called the limit of elasticity. If the extensions under gradually increasing loads were measured by means of a magnifying apparatus, so as to determine them accurately, and were plotted, as in Fig. 25, Plate 36—the abscissæ representing loads and the ordinates extensions—he had always found that the diagram so obtained for commercial pure copper began as a curve from the origin, as shown by the full line; on releasing the test-piece after each successive load had been applied, there was found to be a permanent set from the very beginning. When the same specimen was tested again a second time, the curve approximated much more towards a straight line, as shown by the dotted line, than the curve of the specimen when first tested. For this reason he maintained that copper had no more real limit of elasticity than cast-iron had. The copper behaved precisely like cast-iron; when first tested it invariably showed sets from the beginning, if only the apparatus used was sufficiently delicate to magnify the extensions. It was a curious fact that the early development of permanent set did not seem to occur in all the alloys of copper. Some alloys—manganese-bronze, for instance—showed it distinctly; whereas the extension diagram for phosphor-bronze and two or three other alloys started as a straight line, like that shown dotted in Fig. 25, and a clearly marked limit of elasticity occurred at some point along it.

In the same tests he had also found a rather curious point, upon which Professor Roberts-Austen might be able to throw some light: namely the relation which existed between the shearing strength and the tensile strength of copper and its alloys. For wrought-iron and steel the shearing strength was usually about 80 per cent. of the tensile strength. For copper, on which he had made a large number of tests, it was considerably higher, amounting to 86·7 per cent.; and he had never obtained so high a ratio for iron or steel. On the other hand for alloys of copper it was usually much lower: for example, naval brass had a ratio of 55·8 per cent., which was extremely low; it had a high tensile strength, but the shearing strength was comparatively low. For phosphor-bronze when rolled, the shearing strength was only 63 per cent. of the tensile strength; but phosphor-bronze cast, which was identical in tensile strength with rolled, gave the extraordinary result of a much higher shearing strength than tensile strength, the ratio being 113 to 100.

(Professor T. Hudson Beare.)

Reference was made in page 105 to Young's modulus of elasticity, which had been alluded to also by Professor Kennedy. He could not himself believe that the atomic volume would have much influence upon the elasticity, because, as pointed out by Professor Kennedy (page 149), throughout almost all the steels dealt with in engineering work, down to the purest commercial wrought-iron, hardly any difference was found in their modulus of elasticity. Instancing another case, in a number of experiments with delta metal and naval brass, notwithstanding they were so different in their composition, he had found almost precisely the same modulus of elasticity: namely 14,360,000 lbs. per square inch for the former, and 14,397,000 for the latter. In nearly all the well-known alloys of copper the modulus of elasticity had about these values.

In regard to the coefficient of contraction, which was defined in page 119 as the ratio of the final area to the original area, in most records of tests it was more usual he believed to speak of the contraction of area as the ratio of the change or difference of area or the lost area to the original area. For the sake of comparison therefore he suggested that it might be worth while to put the coefficient in this form in Table 1.

In carrying out a large number of tests for ascertaining the influence of heat upon the tensile strength of copper and of some of the copper alloys, the method he had adopted was somewhat different from that described by Professor Roberts-Austen (page 112), as he had himself always used an oil bath for heating the specimen under test. As shown in Figs. 26 and 27, Plate 37, the specimen S, except the ends which were held by the machine clips, was enclosed in two pieces of thin triblet tube T, one sliding over the other. The outer end of each tube was closed and made a tight fit to the specimen by a sort of stuffing-box, so that any slight contraction of area at these points was automatically followed up, and the ends were thus kept quite oil-tight. As the specimen stretched, the two pieces of tube allowed this to take place by sliding over each other, the length of their overlap being of course made longer than the extension of the specimen was likely to be. Holes H were cut in the top of the tubes, for pouring oil in, and inserting thermometers and the extension-measuring gear. There was no difficulty in keeping the oil in. The oil was heated by means of Bunsen burners, enabling the temperature to be kept steady; the latter was measured by a special form of mercury thermometer. No difficulty had been found in obtaining almost uniform temperature through the whole length of the specimen; at the ends the temperature was only slightly below that at the centre; the specimen was kept so long a time in the bath that it must have acquired the same temperature as the oil.

Although the analyses of Mr. Dean's fire-box plates had been called in question because they seemed incompatible with the electrical conductivities, yet he suggested that the analyses might perhaps be correct after all, in view of the curious results, mentioned in page 137, which had been obtained in recent experiments by Professors Dewar and Fleming on the electrical conductivities of pure metals and alloys, and the influence thereon of very small quantities of impurities. The electrical resistances he believed had been found to be largely increased by very small percentages of impurities. It seemed possible therefore that one or other of these numerous impurities, of which he had no idea that copper contained so many, might be the cause of the low conductivities, which certainly appeared peculiar when compared with the percentage of pure copper shown by the analyses.

Mr. Thomas Instone asked whether the figures had not been transposed in the two columns of conductivity (page 144). It was usually found that copper when soft, that is annealed, had a higher conductivity than the same copper when hard; but the figures there given showed the exact contrary, with the one exception of No. 18. If they were correct, he should be glad to have an explanation of that point.

Mr. William Gowland said it was quite true that pure copper had a higher conductivity when soft than when hard; but with impure copper that was not the case, and there was no rule. Having made many hundreds of determinations of electrical conductivities,

(Mr. William Gowland.)

he had found that in copper containing much impurity the conductivity was sometimes higher when the metal was hard, and sometimes lower. There was no rule when the copper was so impure as to have only a low conductivity varying from 30 up to 70 per cent.

Mr. Joseph Tomlinson, Past-President, occupying the chair at the request of the President, thought the Members would all agree with him that the investigation undertaken by Professor Roberts-Austen was sufficiently extensive. The question of copper, dealt with in part of the present report, was one in which he himself, as an old locomotive man, was greatly interested, as it was a question of such large importance on all railways. For many years of his earlier experience he used to consider it a very bad result indeed with the old-fashioned engines unless their fire-boxes had a life of something like 400,000 or 460,000 miles; but he was sorry to say that now it was less than 260,000. So wide a difference was a most serious matter. He had never been able to explain it properly, except on the theory that the electricians had practically taken the life out of the fire-boxes by insisting upon a high conductivity and great purity in copper. Some of the impurities, such as tin, iron, and arsenic, he had always maintained were not at all deleterious in locomotive fire-boxes. His reason for this opinion was that formerly nothing was used for the purpose except native copper, that is, Cornish copper, which, as was well known, always contained a fairly good quantity of arsenic, and, as far as he could remember, a small percentage of tin, fairly traceable, and likewise a little iron. These he had always put down as the hardening elements, which had enabled the good results he had mentioned to be got out of the small fire-boxes and with the hard coke then used. Although the use of hard coke had now been given up, yet nothing like the length of wear could be got out of the modern fire-boxes, even with the soft coal now burnt. It must readily be admitted that a good deal else had been done to shorten the life of the fire-box, because a fire-box was expected to do a great deal more in a given time now than it used to do formerly. Owing to the larger sizes of the present engines and their fire-boxes, and the higher speeds of running, and the larger quantity of coal consumed per square foot of grate per hour, there must of necessity be more internal abrasion of the fire-boxes than was caused originally, notwithstanding they were now working with a soft coal, instead of with the hard coke formerly used by which everything was cut away. The tubes also had been affected exactly in the same way. Formerly a mileage of from 190,000 to 230,000 miles used to be got out of a set of brass tubes, made from the same mixture of metal and of the same size as those at present used; but now nothing like that mileage could be got, and many of the railways had been trying pure copper tubes, which were rather expensive, and so far as he could learn the results did not compensate for their increased cost.

To Mr. Dean the Research Committee were much obliged for his kindness in contributing his paper at their special request, in order that it might be read in connection with the present report. One thing at least which was rendered pretty clear by these analyses was that all the plates which contained any reasonable percentage of arsenic were the best. But there were some most extraordinary results, which served to show how difficult it was at present to arrive at any general conclusion. Thus sample No. 1 in Table 2 was from a fire-box which had run 463,660 miles and was still running. No. 4, which was no longer running, had been worn out and broken up at only 177,633 miles. No. 7 had run 223,801 miles; No. 8, 72,676 miles; No. 11, 72,247 miles; and No. 18, only 54,564 miles. These low mileages he considered must be exceptional; for if the average were anything like so small, it would not be possible to keep the locomotives going at 2½*d.* per mile and to renew them. The sulphur and the phosphorus need not be dealt with, because all of each was practically taken out in refining the copper. Nickel did seem to help in the same way as arsenic; where it was present in any quantity there was an improvement in the value of the plate. Each sample analyzed was the representative of only one plate in the fire-box, which under the best conditions must consist of at least three plates. Moreover fire-boxes did not always fail in the same place; sometimes they failed at the top, sometimes between the

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tubes, and sometimes below the tubes; but more especially just now with coal fires they failed just above the fire-bars, where the greatest intensity of the heat occurred. In olden times they used to fail practically all over. For the greater deterioration in modern fireboxes, the extra duty which he had mentioned as being now got out of them must be one cause: but the greater heat was not sufficient to account for all the reduction in mileage. He hoped therefore that Mr. Dean would not let this question drop, while there was still room for further investigation in order to solve what was at present so great a puzzle to locomotive engineers, who would be most thankful to have it cleared up.

Professor Roberts-Austen, in reply to the enquiry (page 150) whether the density of copper, which had been given in page 108 as varying with the mode of preparation, was really that of the mass of the metal itself, said the statement that it varied from 8·0 to 8·2 when electrically deposited from the acetate was given on the authority of Schützenberger, and had reference to the actual substance of the metal itself, not to any alteration of its porosity. Moreover the copper so precipitated had great chemical activity; it oxidized rapidly in air, becoming covered with a brilliant peacock-tinted film; and he thought therefore there was no doubt that it was a real allotropic modification of copper, as alleged by Schützenberger and admitted by many French authorities.

As to whether there were really true "galleries" left through glass (page 150) by chasing out the sodium atoms from the sodium contained in the glass, as already mentioned the passages so left had been likened by Tegetmeier to worm-holes. The fact was that the original sodium atoms contained in the glass were driven out from the glass on the pure-mercury side; and then sodium atoms released from the amalgam on the other side took their place, gradually forcing them along atom by atom. The potassium, when it was substituted for the sodium on the amalgam side, could not force forward the sodium atoms contained in the glass, on account of its atoms being half as large again as those of sodium; it would have to cut a way for itself, so to speak, which of course it could not do. As expressed by Professor Kennedy, the channels in the glass thus acted the part of a sieve, through which atoms or molecules might, as it were, be sifted or filtered. So much interest did the Committee feel in these experiments, that they had instructed him to repeat them with the view of verifying the original observations. The only difficulty appeared to be the powerful electro-motive force required; and he hoped that before the next report some more details would be forthcoming in confirmation and amplification of the extremely interesting experiments made by Tegetmeier.

In regard to the final area of the copper rods fractured in the tensile tests, he agreed with Professor Kennedy's criticism (page 151). So little confidence did he place upon it, that he had not used it for any practical purposes, but had used only the original area.

To Mr. Herbert Tomlinson's conclusion respecting the relation between the modulus of elasticity and the atomic volume of metals some exception had been taken by Professor Kennedy (page 149), who was inclined to doubt whether the modulus of elasticity was influenced by the atomic volume of the added element; and he had cited the fact that in steel containing from 0·2 up to 0·5 per cent. of carbon the modulus of elasticity remained approximately the same. Even in Swedish iron there was a minute amount of carbon; and in all varieties of steel the same element carbon was always present, having the same atomic volume in all those cases. It might be that it was merely a question of variation of the amount of that same element, and that the variation was not sufficient to make a great variation in the modulus of elasticity. Again the delta metal referred to by Professor Beare (page 180) contained not a small quantity of impurity, but a large quantity; it was practically an alloy, and there was no reason why it should not have a particular modulus of elasticity of its own, which might or might not happen to agree with Young's modulus in the case of brass. In delta metal it was not a question of a small quantity of an added element, but of a quantity so large as to constitute a true alloy, which might have its own peculiar modulus.

The remarks of Mr. Arnold and Mr. Hadfield, which might almost be said to constitute supplementary papers, had rather more

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bearing upon the first report, discussed eighteen months ago, than upon the present. To the former he would wait to reply until his experiments were published in detail. The view that the existence of β or hard iron had anything to do with the hardness of hardened steel was objected to by both speakers; but it was with the greatest pleasure that he understood from them that this view, for the promulgation of which M. Osmond and himself were responsible, was being widely accepted and taught. It had been argued by Mr. Arnold (page 153) that, if this theory were correct, a bar of wrought-iron might be prepared in such a way that a chilled cast-iron roll could be turned with it. Such an inference however was not warranted; for there was needed the presence of a suitable element for enabling the quenched hard iron to retain its hard form. In this respect he agreed in thinking that carbon had the pre-eminence over all other elements; nothing, so far as was yet known, could approach it in this particular, or diminish its superiority in the slightest. It was also highly gratifying to learn that the experimental method detailed in the first report had now been adopted by Mr. Arnold (page 154); and he congratulated him heartily on adopting—so far as could be gathered from a glance at the book of curves which had been exhibited (page 155)—M. Osmond's method of plotting the results, and also on succeeding in dealing with larger pieces of pure iron or of steel, and studying their cooling properties. [See also pages 195–8.] There could be no doubt whatever that the results so arrived at would be of value. The cooling curve shown in Fig. 24, Plate 36, from a piece of rather highly carburized steel, presented a remarkably good illustration of the intermediate point Ar2 of recalescence, of which the importance and significance had been dwelt on by Mr. Arnold (page 155). In this particular instance the curve had been drawn on a travelling sheet of paper at a distance, like the curves of which the meeting had already witnessed the tracing by means of the spot of light: with the result that the point of recalescence was largely magnified in its duration. The sensitized plate of the pyrometer, at a distance of only 4 feet from the galvanometer mirror, was here replaced by the sheet of paper at a distance of about 15 feet, whereby the curve was magnified nearly four times, and the lengths of the breaks or points of recalescence were correspondingly drawn out. However troublesome and cumbersome a method therefore the use of a screen or sheet of paper at such a distance might seem to be, it was nevertheless evident what an extremely delicate means it presented of examining more in detail any particularly important points in the cooling curve, such as these points of recalescence.

The value of the microscope in physical research (page 155) he had always appreciated to the full, and he had constantly availed himself of its aid in all investigations to which it was applicable. Where however information was sought as to the invisible molecules which formed the basis of the atomic theory, and not in reference to particles capable of being revealed to the eye by the microscope, there seemed to him to be no opportunity for having recourse to its magnifying power however great.

From a conversation he had had with Mr. Hadfield, he gathered that the possibility of iron existing in an allotropic state, as phosphorus and sulphur could, was not denied by the latter, though he failed to distinguish between the hardness or softness of the *atoms*, and the hardness or softness of the *mass*. It was quite possible for a metal to have hard atoms and yet a soft mass, or soft atoms constituting a hard mass. Independent testimony, of the existence of which he had not previously been aware, had been furnished by Mr. Gowland (page 175), who had adduced an instance proving that this did actually occur in metallurgy. In a mass of silver so brittle that it could not be rolled, individual grains could be separated and flattened out: the mass as a whole was comparatively hard, yet the individual grains were soft and malleable.

The statement, in however guarded a way it might be made, that chromium and tungsten could be considered as softeners of steel, had been objected to by Mr. Hadfield (pages 162–3); but it must be borne in mind that nothing was known as yet about the action either of tungsten or of chromium on really pure iron. The nearest approach to pure iron contained 0·2 per cent. of carbon, and even so small a percentage might be sufficient to constitute a distinct triple compound having a peculiar behaviour of its own, either chromium-

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carbon-iron or tungsten-carbon-iron. With regard to chromium itself it should be borne in mind that its atomic volume (7·7) was so close to the atomic volume of iron itself (7·2) that if the atomic-volume theory held good its action ought to be almost neutral. For the excellent work done by Mr. Hadfield in producing various entirely new series of alloys, not only of manganese and iron, but of chromium and iron, and others, he had a great admiration; it afforded a conspicuous illustration of the fact that, although their methods of observation were somewhat different, both practical and scientific men were alike working on the same lines.

In reply to Mr. Blount's question (page 165), the test pieces usually broke near the middle of their length; and it was probable that, as suggested by him, there was some difference between the temperature at the middle and that at the ends of the pieces, though this difference was probably not more than a few degrees.

The results arrived at by Dr. Watson (pages 168–174) he regarded as of the greatest value, and if they had been published previously the Research Committee would have been very glad to have been enabled to make use of them; as it was, he was thankful they had been elicited in connection with the present report and would be published with it, as he considered they bore so close a relation to it that they might fairly be regarded as forming an integral part of the report itself. The same might be said of Mr. Gowland's interesting remarks (page 175) on bismuth and silver; and he need scarcely add how important it was to the Research Committee that men of such great practical knowledge in their respective branches of metallurgy should give them the benefit of their ripe experience.

With regard to Dr. Watson's preference for using phosphorus as a de-oxidizer in melting copper for casting (page 168), in planning the present research he had deliberately rejected this method, from the fear that a minute quantity of phosphorus would be retained by the copper and would modify its mechanical properties. It looked as if, in measuring the elongation of certain test-pieces through the short length of only four inches, the constricted portions near the break had not been rejected, as was usually done by engineers; and the unduly high elongations seemed to be owing to the neglect of this precaution. In the tests given in page 170, the strength appeared to be rather low for rolled strips. With regard to the amount of oxygen in the specimen rods dealt with in the report, he had every confidence in the analyses made by Mr. Gibb, who was a skilful analyst.

The points raised by Professor Beare (pages 179–180) he would carefully consider in detail. As to permanent set commencing in copper from the very first application of the load, he was a little doubtful; but he frankly confessed that he considered the weakest part of the whole investigation was the determination of the elastic limit. He was inclined to think that the presence of an element of larger atomic volume than that of copper was what did enable the metal to break down so quickly. If the copper were perfectly pure, he thought it would be found that it would not have a permanent set from the first application of the load; but this was a matter of doubt, which could be decided only by further experiment. The result thus far as a whole showed in his opinion how correct were the views of Mr. Tomlinson (pages 182–4), and how important it was that the question of copper fire-boxes in locomotives should be further investigated, this portion of the work being mainly the result of Mr. Tomlinson's initiative. Attention might be called to the fire-box mentioned on page 138, which had had the extraordinary life of 500,000 miles. It would be noticed that the copper contained not only arsenic, but also 0·3 per cent. of nickel; and he was inclined to think that nickel played a far more important part than had hitherto been recognised. When a fire-box exhibited such remarkable endurance, while at the same time such a highly complex constitution was revealed by analysis, it might appear to be almost hopeless to arrive at the true explanation of its durability. But now that a clear distinct mode of action upon copper had been assigned to bismuth and to arsenic, and now that experiments with nickel were in progress, the investigation seemed to him to be in a fair way for a successful issue.

Mr. Tomlinson, in inviting the Members to join him in a most cordial vote of thanks to the author for the great amount of time and

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attention he had devoted to this subject, was sure all would wish thereby to express their appreciation of the labours undertaken by Professor Roberts-Austen on behalf of the Alloys Research Committee. The investigations he was conducting were indeed inexhaustible, marvellously interesting, useful, and instructive, especially to engineers. They might still be carried much further, he thought, so as to find out many things even in which engineers might perhaps not imagine themselves to be so specially interested. All would agree that the results already arrived at were such as augured well for yet further success in the study of alloys.

M. ANDRÉ LE CHATELIER, Toulon Dockyard, wrote that he desired to thank Professor Roberts-Austen for the interest he had taken in the writer's investigations in connection with the very questions which had been cleared up in so remarkable a way by his own beautiful experiments. In investigating the influence of small quantities of foreign ingredients or impurities upon metals, it appeared to him indispensable to distinguish, as was done in the present report, the case of metal which was simply cast, from that of the same metal after it had undergone mechanical working either by forging, rolling, or drawing. His own experience in regard to this distinction led him to offer the following contribution to the discussion of the report.

First, in regard to cast metals, it has been shown by Professor Roberts-Austen's experiments on gold cast with small quantities of other metals that those having a greater atomic volume than that of gold (10·2) diminish its tenacity and ductility, while those having a smaller atomic volume increase them. There are however some exceptions: thus iridium (15·3), lithium (11·8), and aluminium (10·8), do not alter the qualities of cast gold. The same exceptions occur also with other metals: thus silicon (11·2) produces no injurious effect upon iron (7·2); and the same is the case with aluminium (10·8) in copper (7·1). This fact led him to imagine that the effect of impurities might arise from some other cause, and might be due to their influence on crystallization: this influence resulting either from their own fusibility, or from the fusibility of the compounds which they formed with the metal. The influence of impurities on crystallization has been clearly shown in regard to steel by MM. Osmond and Werth. Thus carbon and phosphorus, whose atomic volumes differ so widely as 3·6 and 13·5, nevertheless produce similar effects on the crystallization of steel. Agreeably with the discoveries of MM. Osmond and Werth, the same should therefore be the case he supposes for all metals. It must be borne in mind that the tenacity and ductility of a cast metal depend almost solely on its state of crystallization; a highly crystalline metal has no tenacity. On the other hand the tenacity varies largely according to the manner in which the metal has been cast; it is much greater when the cooling has been rapid, as for instance when the metal has been run into a metallic mould, because then the crystallization is less marked. For these reasons he supposes that the influence of impurities on tenacity arises most of all from their influence on crystallization, and consequently from their own fusibility or that of the compounds they may form with the metal, just as is the case with steel.

Secondly, in regard to metals that have undergone mechanical working, their tenacity and ductility are very different from those of the same metals when simply cast, and must be investigated separately. In his own experiments the writer has invariably found that all impurities, whatsoever they may be, increase the tenacity of the metal: so that the purest metal has the lowest tenacity, at the same time that it possesses the highest ductility. This fact has long been known in regard to iron, of which the tensile strength is increased by every impurity, even by phosphorus and silicon, although their atomic volumes (13·5 and 11·2 respectively) are so much larger than that of iron (7·2). The same fact holds good for copper; when drawn into wire the tenacity of very pure copper does not exceed from 57,000 to 60,000 lbs. per square inch, and cannot be got higher even by repeated drawing. Impure copper, such as ordinary commercial copper, may attain under the same treatment a strength of 71,000 lbs. per square inch; copper cast with one per cent. of aluminium rises to 78,000 lbs.; and the copper alloyed with silicon, which is used for telegraph wires, rises to 128,000 lbs. The tests given by Professor Roberts-Austen in the present report show also that arsenic and antimony increase the tenacity of copper.

On silver the writer has himself experimented, and the following are the particulars of three examples that he tested: No. 1, pure silver (atomic volume 10·2); No. 2, silver alloyed with one per cent. of copper (7·1); No. 3, silver alloyed with one per cent. of tin (16·2). These three samples were drawn down into wire, being passed through the draw-plate a great number of times in order to give them the greatest possible tenacity. Their tensile strength was then as follows: No. 1, 47,000 lbs. per square inch; No. 2, 78,000 lbs.; No. 3, 64,000 lbs. Tin had thus the effect of hardening the silver just as copper did. After annealing at 500° C. or 900° Fahr. the same three examples gave the following results: No. 1, 28,300 lbs. per square inch; No. 2, 32,300 lbs.; No. 3, 32,400 lbs. Here again the effect of tin was the same as that of copper. This example is the more interesting because No. 3 sample containing tin had been crystalline and weak as cast, and the work put upon it gave it the same properties as No. 2 sample containing copper, which immediately after melting had been much stronger than No. 3. On further heating to a high temperature the wires drawn from the three metals, it was found that No. 3 containing tin underwent a rapid change. Thus after five minutes' heating at a bright cherry red the following results were obtained: No. 1, tensile strength 26,700 lbs. per square inch, with 40 per cent. elongation; No. 2, 32,300 lbs., with 40 per cent. elongation; No. 3, tensile strength only 17,100 lbs. per square inch, with only 3 per cent. elongation. Thus No. 3 sample containing tin, which after heating to 500° C. or 900° Fahr. had remained identical with No. 2 containing copper, was completely altered by heating to redness. This arose from its crystallizing at the red heat, just as steel rich in phosphorus crystallizes at 900° to 1,000° C., or 1,600° to 1,800° Fahr., and loses its tensile strength. When however this crystallized sample was passed through the draw-plate again, its crystallization was destroyed, and it recovered the same qualities as the sample containing copper.

These experiments clearly show the difference between the influence of impurities on metal that has simply been cast, and their influence on metal that has undergone mechanical working. In the first case the tenacity is diminished, if the impurity conduces to crystallization. In the second case the tenacity is invariably increased. Nevertheless even after metals have undergone mechanical working, there is some difference in the effect produced by impurities. All of them harden the metal, but some only a little, others much. Thus on iron, carbon has a powerful effect, while phosphorus affects it but slightly. On copper the effect of arsenic and antimony is great. The same is doubtless the case with all metals, and must arise always from the effect of the impurities on their allotropic changes, as has been shown to be the case with iron. This action is closely connected with the law of atomic volumes, as has been shown by M. Osmond in respect to iron. It would be highly interesting to verify the fact for other metals which undergo well-known allotropic changes, such as nickel, zinc, and aluminium.

Mr. John A. F. Aspinall, Member of Council, wrote that it is no doubt essential that more should be ascertained about the impurities found in copper, with a view to improving the durability not only of the copper fire-boxes in locomotives, but also of copper tubes and stays. The tendency in recent years to make the copper if anything too pure has been brought about to some extent by the demand for a higher degree of purity for electrical requirements; and the mode of manufacture with this view has been extended to copper not used for electrical purposes. Analysis alone however does not enable any definite conclusion to be arrived at as to why certain locomotive fire-boxes have worn either badly or well. In a single delivery of a lot of plates the analysis varies remarkably; in a recent lot supplied by first-class makers the arsenic varied from 0·02 to 0·08 per cent.,

(Mr. John A. F. Aspinall.)

the tin from a trace to 0·02, the bismuth from a trace to 0·05, the lead from 0·03 to 0·10, and the cuprous oxide from 0·00 to 0·16 per cent. It appears to the writer that either the copper is not poled enough, or there is some other reason of a mechanical nature which would account for the present defective quality of the metal; for whether the short life now obtained with copper fire-boxes is measured by miles run or by tons of coal burnt, the result is not so good as it was in the early engines built by Messrs. Bury, Curtis, and Kennedy. So far as the mechanical working of the plates is concerned, it is evidently most desirable to obtain copper that will admit of flanging by machinery; this work has still to be done by hand, as no attempts have as yet been successful in flanging copper in hydraulic presses, so far as the writer knows. In dealing with the wear and tear of plates, their abrasion must be considered: round the fire-hole door, and round the sides where the coal is constantly in contact with the plates, a large amount of wear due to mechanical abrasion takes place.

Copper stays used in fire-boxes are a frequent source of trouble; and in order to ascertain what loss of tensile strength is due to heating, the writer recently had a number of copper rods tested of 0·798 inch diameter and 8 inches length. During the test the specimens were heated by encasing them in a copper cylinder with loose cover, containing oil of a high flashing point, Fig. 28, Plate 37; previously to the tensile strain being applied the oil was heated by three Bunsen burners beneath the cylinder to the temperature of 370° Fahr., corresponding with the boiler pressure of 160 lbs. per square inch in the locomotives in which the stays are working; the temperature of the oil was ascertained by a couple of thermometers. The following were the results:—

Tensile Strength, tons per square inch .	14·9 cold	11·9 hot.
Elongation in length of 8 inches, per cent. .	46·5 ,,	42·0 ,,
Reduction of area, per cent. . . .	66·1 ,,	70·3 ,,

The effect of the heating was thus a decrease of 3 tons per square inch in tensile strength, and of 4·5 per cent. in elongation; while the reduction of area increased 4·2 per cent., understanding by reduction the ratio of the lost area to the original area.

Some further tests were tried with ordinary stays of the exact length used in the fire-box, namely $6\frac{1}{2}$ inches, screwed with eleven threads per inch, and one inch diameter to the outside of the thread. With those screwed throughout their entire length the results were:—

Tensile Strength, tons per square inch .	14·8 cold	12·19 hot.
Elongation in length of 3 inches, per cent. .	29·0 „	26·6 „
Reduction of area, per cent. . . .	31·3 „	31·4 „

With stays having the threads turned down for three inches length in the middle to the diameter at the bottom of the thread or 0·86 inch, the results were:—

Tensile Strength, tons per square inch .	14·7 cold	11·4 hot.
Elongation in length of 3 inches, per cent. .	52·5 „	53·9 „
Reduction of area, per cent. . . .	61·3 „	63·9 „

It is the invariable practice to anneal copper carefully before it is used; for if copper stays are used without being annealed, they are much more apt to break. The average of 90 tests showed the result of annealing to be when cold a loss of 10 per cent. in tensile strength, an increase of 15·7 per cent. in elongation, and an increase of 1 per cent. in contraction of area. So far as fire-box copper is concerned, the average of 170 tests when annealed gave 14·25 tons tensile strength when cold, with 42·0 per cent. elongation and 51·6 per cent. contraction of area.

Professor Roberts-Austen added that his friend M. Osmond had written to him with reference to the discussion, and the following was the substance of his letter:—

"As my own researches seem to form the subject of the remarks made by Mr. Arnold (page 153), rather than your second report presented to the Alloys Research Committee, my observations will naturally refer more to those remarks than to the report itself. Now that Mr. Arnold has taken the trouble to repeat my experiments, he seems to appreciate them more truly.

"In the experimental portion of Mr. Arnold's work he appears to have attempted, firstly to render the galvanometer more sensitive, secondly to use heavier samples for his experiments than I did, and

(Professor Roberts-Austen.)

thirdly to obtain a greater number of curves from metal during the process of heating, in order to facilitate the comparison of these with the cooling curves. The advantage to be derived from the first two of these attempts is not quite evident, as efforts have hitherto been directed to reducing as far as practicable the weight of the piece of metal experimented upon, with the object of diminishing the differences of temperature between different parts of the piece. On the other hand I do not fail to appreciate the advantage of a larger number of heating curves, having myself taken many more than were published; this I was led to do, because my apparatus did not admit of regulating the heating as perfectly as was desirable. It does not appear however that the existence has been discovered of any additional critical point which had escaped my observation in the heating or cooling of iron and steel.

"The meaning to be assigned to the several critical points is a question which may naturally call forth a difference of opinion. About the point Ar1 there is no discussion. The intermediate point Ar2 of recalescence (page 155) had already, prior to Mr. Arnold's researches, been distinctly separated by myself from the higher point Ar3, by means of an experiment of which the results have at present been only briefly indicated in a report, as yet subject to revision, which was presented fourteen months ago to the "Commission des Méthodes des essais des Matériaux de construction." When discussing in my paper on the critical points of iron and steel (Journal of the Iron and Steel Institute, 1890, part 1, page 38) the experiments of Hopkinson and Ledeboer, I thought it possible to identify with the point Ar3 the appearance of magnetic permeability in iron and steel. By subsequent direct experiments however, which have been confirmed by yourself and Mr. Herbert Tomlinson, it was found that, in cooling curves, the appearance of magnetism in iron coincides exactly with the intermediate point Ar2, and not with the higher point Ar3. It is thus clear that the two points Ar2 and Ar3 are independent of each other, as I have always considered possible; and the contrary supposition has only been advanced by me provisionally and with reservation. Now it appears incontestable that the point Ar2 corresponds with an allotropic modification of iron, because magnetic permeability is a property of iron itself: and this view receives support from Mr. Arnold's experiments on crystallization, although his results do not seem to be conclusive. That a change in crystalline system is produced at the point Ar2 has every semblance of being true, although I have not myself succeeded in verifying the fact; such a change would indeed be a natural corollary of an allotropic transformation. The development of a crystalline grain corresponds with the point *b* on Chernoff's scale, that is, the temperature below which if steel be heated it does not change its structure in cooling, whether cooled slowly or quickly (Proceedings 1880, page 291). This point occurs at a much higher temperature than Ar2, and higher even than Ar3; and as soon as crystallization begins to appear, it is developed progressively, and without any evolution of heat that I have been able to detect. After all, with respect to the point Ar2 there does not seem to remain any difference between my own view and Mr. Arnold's.

"As to the higher point Ar3 being regarded as due to a combination of iron with hydrogen (page 158), this view, though at first sight plausible, appears to be directly contradicted, without referring to other less conclusive reasons, firstly by your own experiments made in vacuo after the extraction of gas from the iron, and secondly by similar experiments repeated by Mr. Arnold, who has himself shown that the point Ar3, instead of disappearing in proportion to the elimination of hydrogen, occurs more sharply between narrower limits of temperature (page 159). From this evidence, which seems so strong as to be almost conclusive, it would follow that the point Ar3 is due to the iron itself, as I have always represented it to be.

"Now that it is demonstrated that Ar3 and Ar2 are independent, it need only be added here that there must exist three allotropic forms of iron, instead of two: namely the form α existing at temperatures below Ar1; the form β, between Ar1 and Ar2; and the form γ, above Ar3. What may be the respective parts played by β iron and by γ iron in the hardening of steel, and in the properties of manganese steels and nickel steels, is a problem difficult to solve at present; it is certain that much remains to be discovered.

(Professor Roberts-Austen.)
Meanwhile the conscientious work undertaken by Mr. Arnold, in his endeavour to controvert the views promulgated by you and by myself, appears thus far to have furnished only additional reasons for holding these views more tenaciously."

For the present this letter would be sufficient, Professor Roberts-Austen thought, to cover all the points raised by Mr. Arnold.

Mr. DEAN wrote that the chief point raised in connection with his own paper appeared to be the incompatibility of the chemical analyses with the electrical conductivity tests (pages 173 and 176). He had himself no practical experience of electrical conductivity tests; but judging from Mr. Gowland's remarks (page 181) with reference to the inconsistency of the results obtained on annealing copper containing impurities, and also from the figures furnished by Mr. Crompton, it appeared that differences in the physical condition of the copper, dependent on the previous mechanical treatment and the amount of annealing it had received, afforded reasons for a considerable variation in conductivity, apart from the amount of impurities present. From the remarks of Professor Beare (page 181) he inferred that the experiments of Professors Dewar and Fleming—on the electrical conductivities of pure metals and alloys, and the influence thereon of very small quantities of impurities—had some bearing on the matter. His own analyses had been conducted with great care and by the best methods known. The arsenic and the combined oxygen had been estimated by methods devised by Sir Frederick Abel. The reliability of the method for the estimation of arsenic had been tested by adding known quantities of arsenic to comparatively pure copper, and analysing; and the results obtained had been satisfactory.

EXPERIMENTS ON THE DRAUGHT PRODUCED IN DIFFERENT PARTS OF A LOCOMOTIVE BOILER WHEN RUNNING.

By Mr. JOHN A. F. ASPINALL, Member of Council,
Chief Mechanical Engineer, Lancashire and Yorkshire Railway.

The experiments here described were tried some time ago under the writer's direction, in order to illustrate the varying conditions under which a locomotive boiler is called upon to work during different portions of a journey. They were made on a four-wheel coupled bogie express passenger engine on the Lancashire and Yorkshire Railway, taking a passenger train from Victoria Station, Manchester, to Chapel Street Station, Southport, and back, a distance of 35 miles each way, with an intermediate stoppage about midway at Wigan. The train was made up of engine, tender, and ten coaches, as shown in Fig. 1, Plate 38; the total length over the buffers was 386 feet, and the total weight about 200 tons. The engine had cylinders 18 inches diameter and 26 inches stroke; coupled wheels 7 ft. 3 ins. diameter; heating surface, tubes 1108·75 square feet, fire-box 107·68, total 1216·43 square feet; fire-grate area $18\frac{3}{4}$ square feet. The total weight of the engine in working order was 44·8 tons, of which the driving wheels carried 16·5 tons, the trailing wheels 14·5, and the bogie 13·8 tons. The tender, having a tank of 1,800 gallons capacity, weighed with water and coal 26·1 tons. The total weight of engine and tender was therefore 70·9 tons. In both the outward and the return journey the rails were dry and the wind moderate.

Vacuum pipes were fixed in the chimney and smoke-box in the four positions A, B, C, D, shown in Figs. 2 and 3, Plate 38. From these pipes india-rubber tubing was led to four water-gauges filled with coloured water and placed on a board on the platform in a convenient position for the observer to read them readily. A fifth pipe was put through one of the bottom tubes into the fire-box, and

(*continued on page* 202.)

Outward Journey, 35 *miles,*
from Victoria Station, Manchester, to Chapel Street Station, Southport.

Average Speed 48·4 *miles per hour.*

Distance from Manchester.	Gradient.	Speed.	Boiler Pressure per square inch above atm.	Vacuum, column of water.			Pressure in Ashpan.
		Miles per hour.		Chimney.	Smoke-box.	Brick Arch.	Column of water.
Miles.		Miles.	Lbs.	Inches.	Inches.	Inches.	Inch.
1·84	Rising	35	153	13·9	4	2	0·25
3·00	Rising	38	155	18	4·9	2·4	0·25
4·00	Rising	36	155	18	4·9	2·4	0·25
4·70	Rising	40	155	18	4·9	2·4	0·25
5·90	Falling	50	157	18	4·9	2·4	0·25
7·50	Rising	50	160	18	4·9	2·4	0·25
8·90	Falling	52	145	15	4	2	0·50
10·85	Falling	57	140	15	4	2	0·75
11·85	Rising	50	140	15	4	2	0·75
12·90	Level	52	152	15	4	2	0·75
14·59	Rising	52	145	9	4	1	0·75
16·70	Rising	48	140	7	3	1	0·50
18·85	Falling	42	155	9	4	1	0·25
19·70	Rising	42	153	9	4	1	0·25
21·50	Rising	50	160	15	5	2	0·50
22·45	Falling	54	155	15	5	2	0·50
23·70	Falling	55	155	7	4	1	0·75
25·75	Level	56	158	7	4	1	0·75
27·40	Rising	52	160	10	5	2	0·75
29·40	Rising	54	155	10	5	2	0·75
30·48	Level	54	155	10	4	1	0·75
32·60	Level	55	150	15	4	1	0·75

Return Journey, 35 *miles,*
from Chapel Street Station, Southport, to Victoria Station, Manchester.

Average Speed 40 *miles per hour.*

Distance from Manchester.	Gradient.	Speed. Miles per hour.	Boiler Pressure per square inch above atm.	Vacuum, column of water.			Pressure in Ashpan.
				Chimney.	Smoke-box.	Brick Arch.	Column of Water.
Miles.		Miles.	Lbs.	Inches.	Inches.	Inches.	Inch.
34·30	Falling	10	150	—	—	—	—
33·90	Falling	32	155	12	6	3	0·25
33·00	Level	40	155	12	6	3	0·25
31·00	Falling	46	154	15	7	3	0·50
30·20	Rising	47	150	15	7	3	0·50
28·40	Rising	48	152	15	7	3	0·50
26·20	Rising	52	152	12	5	2	0·50
24·30	Rising	46	154	12	5	2	0·50
23·20	Rising	47	152	15	6	2·5	0·50
21·60	Falling	47	155	12	5	2	0·50
19·90	Falling	48	158	12	5	2	0·50
17·90	Rising	19	155	—	—	—	—
16·90	Level	35	155	17	5	2·2	0·25
16·00	Rising	35	150	17	5	2·2	0·25
15·20	Rising	35	155	18	6	3	0·25
14·00	Rising	40	158	15	5	2	0·50
13·00	Level	46	155	11	5	2	0·75
11·70	Falling	50	152	11	5	2	0·75
10·00	Rising	52	150	13	6	3	0·75
9·00	Rising	46	158	13	6	3	0·75
8·00	Falling	44	152	12	5	2·5	0·75
6·60	Rising	46	152	8	3	1	0·75
5·20	Falling	47	143	11	5·5	2·5	0·50

(continued from page 199.)

turned up so as to stand above the brick arch at E, Fig. 4. Two other pipes were placed at F and G, for measuring the pressure of air at the front and back of the ashpan. The three pipes E, F, G, were also led to water-gauges on the platform with the four others. The orifice of the pipe A was in the centre of the chimney and half way up. The orifice of B was level with the top row of tubes, and half way between the blast-pipe and the tube-plate. The orifice of C was level with the bottom row of tubes, and vertically under B. The orifice of D was level with the middle row of tubes, and half way between the blast-pipe and the smoke-box door. At all these three points in the smoke-box the vacuum was found to be the same The area of opening of the damper in front of the ashpan was 320 square inches.

The results of the observations are recorded in the accompanying tables, pages 200–1; and are also plotted as a diagram in Plates 39 and 40, in which is added a profile of the line, showing the nature of the gradients. It will be seen that the vacuum produced in the chimney varied from 7 to 18 inches of water column; in the smoke-box from 3 to 7 inches; and over the brick arch in the fire-box from 1 to 3 inches. In the ashpan the pressure varied from $\frac{1}{4}$ to $\frac{3}{4}$ inch column of water. The boiler pressure varied from 140 to 160 lbs. per square inch above atmosphere. On the outward journey the greatest speed was 60 miles per hour, and the average was 48·4 miles, including the midway stoppage at Wigan. On the return journey the greatest speed was 55 miles per hour, and the average 40 miles, including the stoppage. The speeds were taken by a Boyer speed recorder.

These experiments the writer thinks illustrate fairly the conditions under which locomotive boilers work upon railways, and show that these conditions are if anything more severe than those to which the boilers are subjected in torpedo boats, where so much trouble has been experienced through leaky tubes. As locomotive boilers under these conditions are seldom troubled with leaky tubes, this fact seems to indicate that, if induced draught were used instead of forced draught in torpedo boats, some of the troubles met with in the latter might be got rid of.

MEMOIRS.

Samuel Stewart Carrick was born in Glasgow on 30th December 1849, and after being educated at Glasgow High School was apprenticed for five years, May 1868 to 1873, with Messrs. Randolph, Elder and Co., marine engineers, Glasgow. On the completion of his apprenticeship he served sixteen months in the drawing office of Messrs. A. and J. Inglis, Pointhouse, near Glasgow. In January 1875 he joined the Union Steamship Co., Southampton, in whose service he remained for nine years until October 1884, working his way up from fourth engineer to chief, which last position he held for the four years prior to his leaving. He was then appointed superintendent engineer to the Shaw, Savill and Albion Co.; and for the two years preceding his death he held conjointly with this the appointment of superintendent engineer to the White Star line for their London service of steamers. On 7th June 1893 he was taken suddenly ill, and died on 17th June, in the forty-fourth year of his age. He became a Member of this Institution in 1888.

Edward Alfred Cowper was born on 10th December 1819 in London, and was the son of Mr. Edward Cowper, professor in the engineering department of King's College, London, who was a fertile inventor in relation to printing machines. In 1834 at the age of fourteen he was apprenticed for seven years to Mr. John Braithwaite, of St. Pancras; and while there invented in 1837 the detonating fog-signal, which was first tried on the Croydon line. In 1841 he went to Messrs. Fox and Henderson, at the London Works, Smethwick, near Birmingham, where for some time he held the post of chief draughtsman and designer. In 1846 he took an active part in promoting the establishment of this Institution, to which he contributed one of the earliest papers (Proceedings October 1847, page 1) on an "inverted-arch suspension-bridge.

During his stay at the London Works he introduced an improved mode of moulding railway chairs (Proceedings July 1851, page 42); and invented and made hydraulic machinery for bending railway-wheel spokes out of flat bars, cutting out horn-plates with dies, cutting out the links for suspension bridges, and other work. In 1851 he returned to London, and commenced practice as a consulting engineer. Two important works testify to his early skill:—the Crystal Palace, formerly the 1851 Exhibition building; and the wrought-iron roof of the railway station, New Street, Birmingham (Proceedings 1854, page 79), the span of which—211 feet—was at the time the largest in existence. He early made his mark in engine design, and advocated the compound engine at a time when it was not yet appreciated; and he was an earnest believer in steam-jacketing. His steam-heated receiver or "hot pot" was tried in H.M.S. "Briton," fitted with compound engines, which attained the economy, at that time (1870) unparalleled, of 1·3 lb. of coal per horse-power per hour. On the invention of the regenerative furnace by Sir William Siemens, he saw its applicability to the purpose of heating the blast for blast-furnaces (Proceedings 1860, page 54), by the use of stoves containing masses of open brickwork, instead of the cast-iron pipes through which the air to be heated had previously been passed. By this means the former temperature of 800° Fahr. in the pipe stoves was increased in the regenerative fire-brick stoves to 1150° and subsequently to 1600°, corresponding with a saving of 4 cwts. of coke per ton of pig-iron. The first of these stoves was built in 1859; and various improvements were subsequently effected up to 1887, both by himself and by his son, Mr. Charles E. Cowper, whom shortly before his death he had taken into partnership; one of the most important improvements was the recent introduction of a honeycomb form of regenerator. Among his other inventions were the modern bicycle wheel, that is, a wire-spoke suspension-wheel with india-rubber tyre; and the "writing telegraph," which has recently been revived as one of the electrical novelties at the Chicago Exhibition. In 1887, in conjunction with Dr. Anderson, he carried out an elaborate investigation with a 5 horse-power engine to test the accuracy of

Joule's conclusions as to the mechanical equivalent of heat, with the result of confirming Joule's equivalent. In addition to those already mentioned he also read papers before this Institution on Brockedon's application of vulcanised india-rubber to pipe-joints (Proceedings October 1848, page 20); on Cugnot's original invention of the locomotive steam-engine for use on common roads (Proceedings 1853, page 33); on a set of blast engines made for the East Indian Iron Co. (Proceedings 1855, page 154); on two pair of horizontal pumping engines (Proceedings 1858, page 46); on the inventions of James Watt, and his models (Proceedings 1883, page 599). His death took place at Weybridge on 9th May 1893, after a brief illness from pneumonia, in the seventy-fourth year of his age. He was an original Member of this Institution from its formation in Birmingham in 1847, and for many years a Member of Council and a Vice-President; and he was President in 1880 and 1881. He was also a Member of Council of the Institution of Civil Engineers, and a member of many other societies.

Henry Hyndman Laird was born at Birkenhead on 21st May 1838, being the fourth son of Mr. John Laird. He was educated at the Birkenhead school, and commenced his shipbuilding training in 1855 in the works of the Messageries Impériales (now Maritimes) at La Ciotat, near Toulon. After remaining there nearly three years he returned to Birkenhead in 1857, and the knowledge he had acquired of naval architecture became of the greatest service to his father's firm. On the retirement of his father from the direction of the firm in 1862 he joined his elder brothers, William and John, as a partner in the firm of Laird Brothers. In the matter of warship design he was singularly successful, and nearly every naval power possesses one or more specimens of work turned out by his firm. Many of these warships have been in action: notably the Chilian torpedo-catchers, "Almirante Condell" and "Almirante Lynch," and the Peruvian turret-ship "Huascar." Besides building many warships for South America and other foreign states, the Birkenhead Works have turned out recently for the British government the "Rattlesnake," and have nearly completed the first-class battle-ship

"Royal Oak" and two gunboats "Onyx" and "Renard" (Proceedings 1891, pages 451–3). For the merchant service equal, if not greater, success has been attained with the Atlantic liner "Columbia" and those of the National line, besides several Channel steamers for the London and North Western, the Great Western, and the Lancashire and Yorkshire Railways, and the City of Dublin Steam Packet Company. Mr. Henry Laird was remarkably cautious, shrewd, and just, and popular with workmen of all ranks. His death took place at Birkenhead from pneumonia, on 26th May 1893, at the age of fifty-five, after a brief illness. He became a Member of this Institution in 1872, and was a Member of Council in 1876–79; he was also a Member of Council of the Institution of Naval Architects.

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SHIP MODEL APPARATUS.

Plate 1.

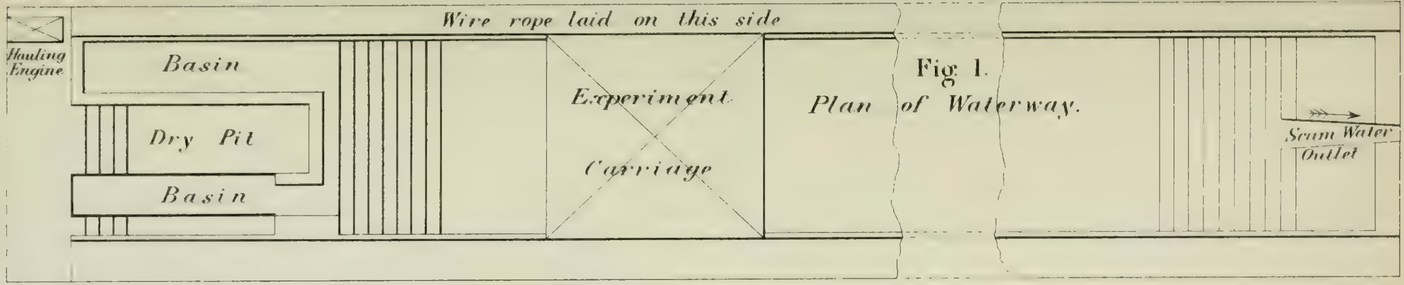

Fig. 1. Plan of Waterway.

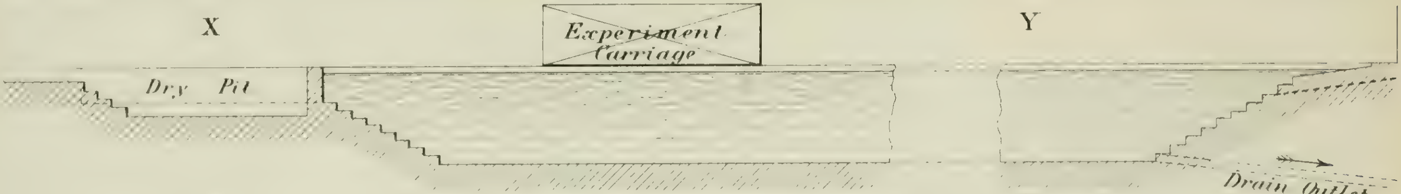

Fig. 2. Longitudinal Section of Waterway.

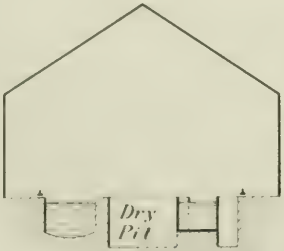

Fig. 3. Transverse Section at X.

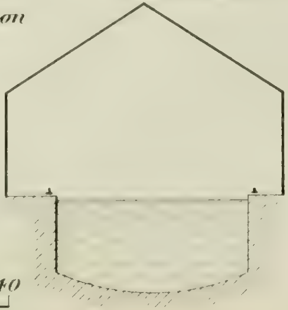

Fig. 4. Transverse Section at Y.

Scale 1/240th

Feet 10 5 0 10 20 30 Feet 40

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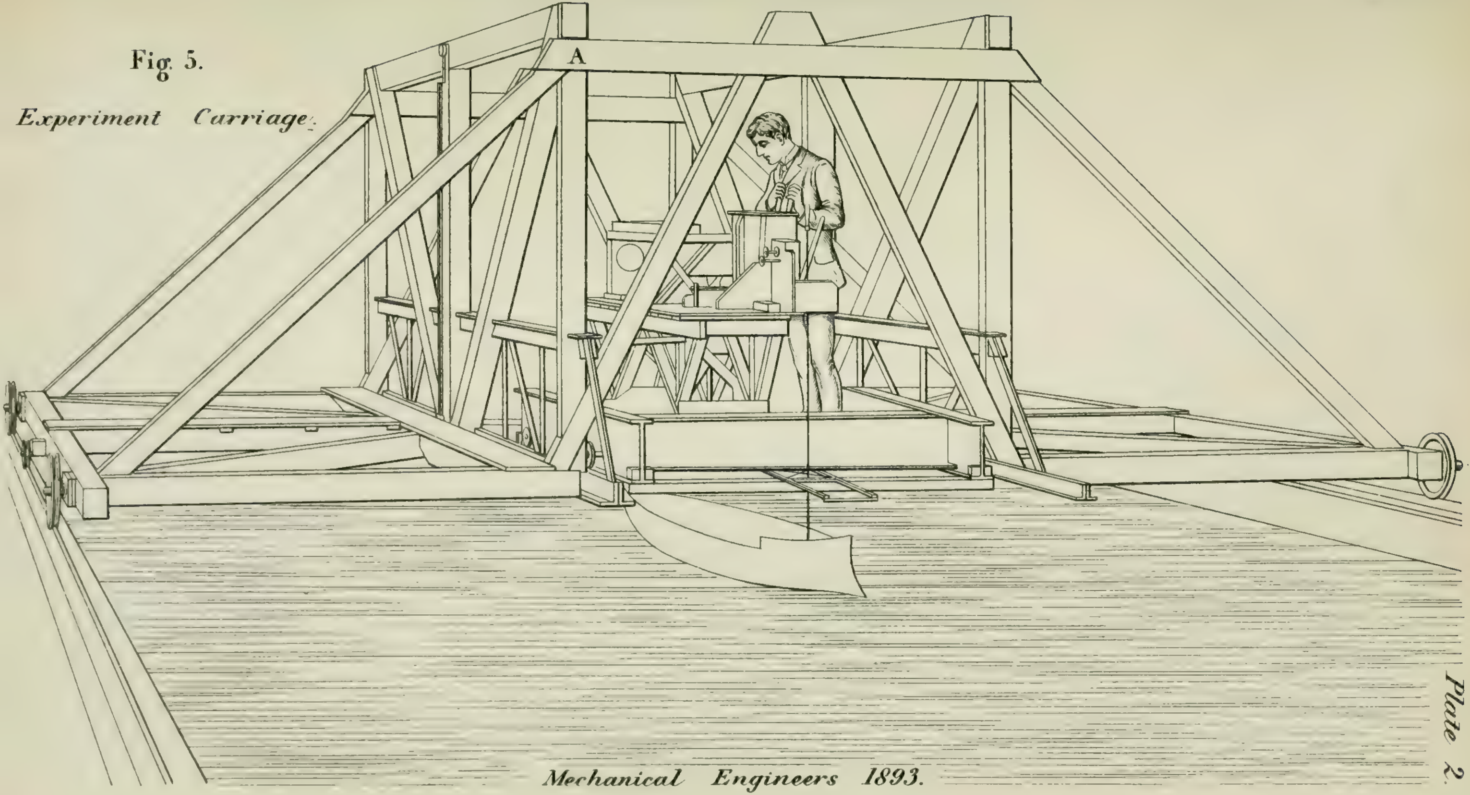
SHIP MODEL APPARATUS.

Fig. 5.

Experiment Carriage.



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SHIP MODEL APPARATUS. *Plate 3.*

Detail of Experiment Carriage.

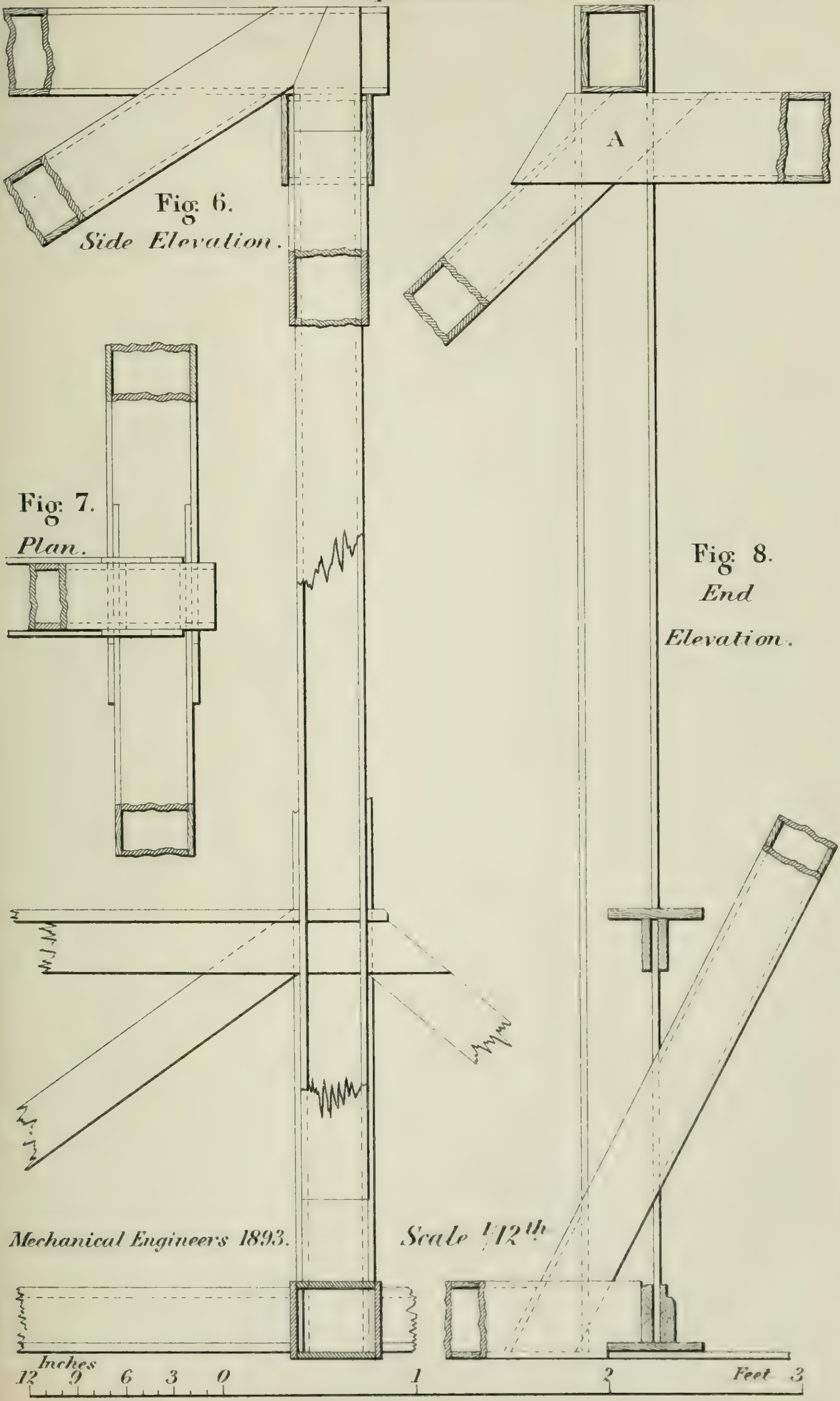


Fig: 6.
Side Elevation.

Fig: 7.
Plan.

Fig: 8.
End Elevation.

Mechanical Engineers 1893.

Scale 1/12th

SHIP MODEL APPARATUS.

Governor.

Fig. 9.
Vertical Section.
Scale 1/6th

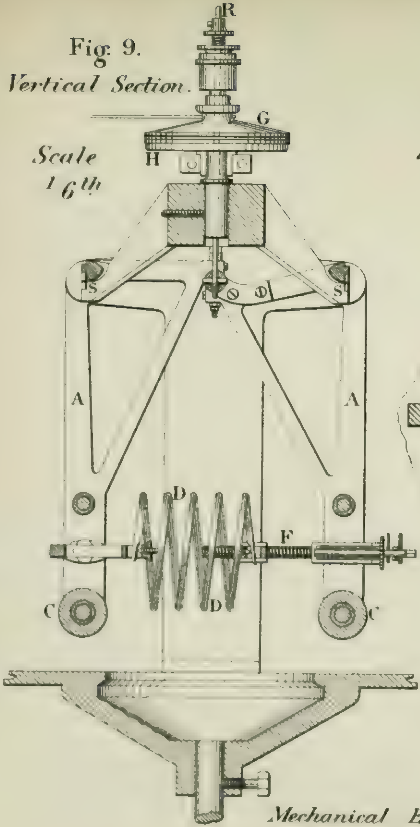


Fig. 11.
Plan.
Scale 1/3rd

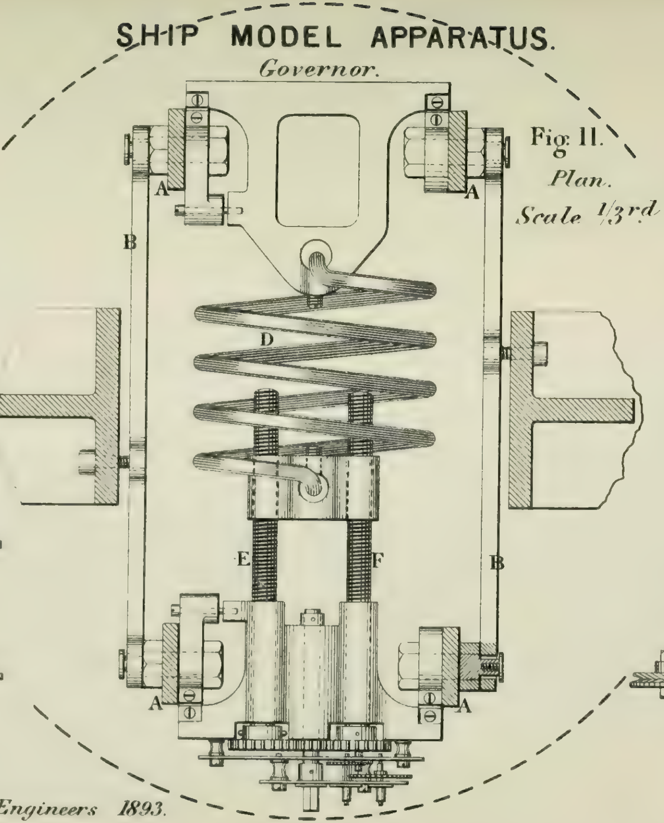
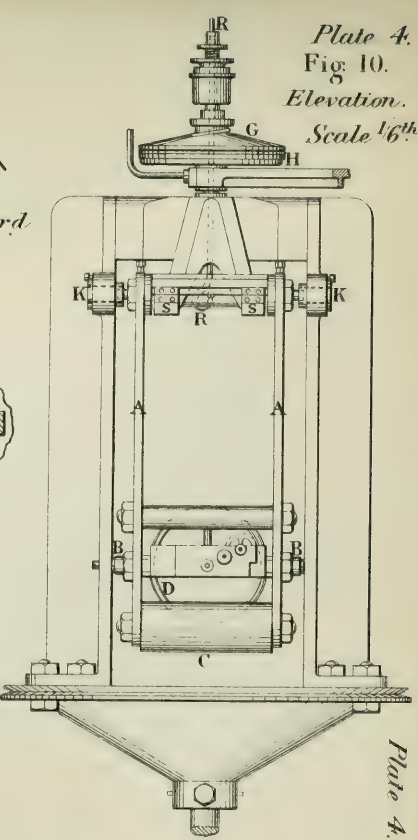


Fig. 10.
Elevation.
Scale 1/6th



SHIP MODEL APPARATUS.

Details of Governor.

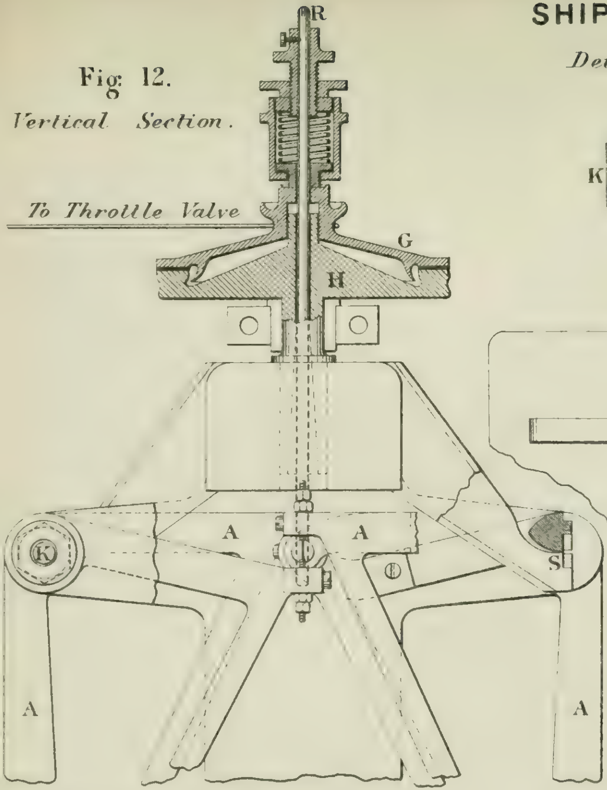


Fig: 12.
Vertical Section.

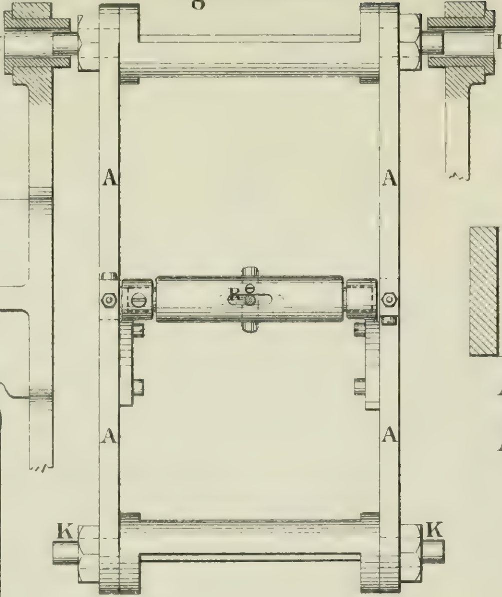


Fig: 14. *Plan.*

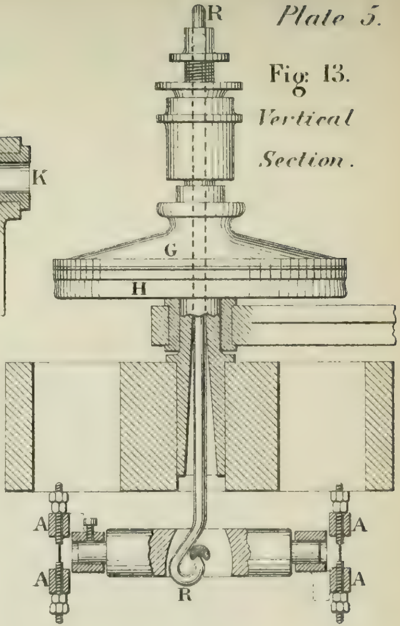


Fig: 13.
Vertical Section.

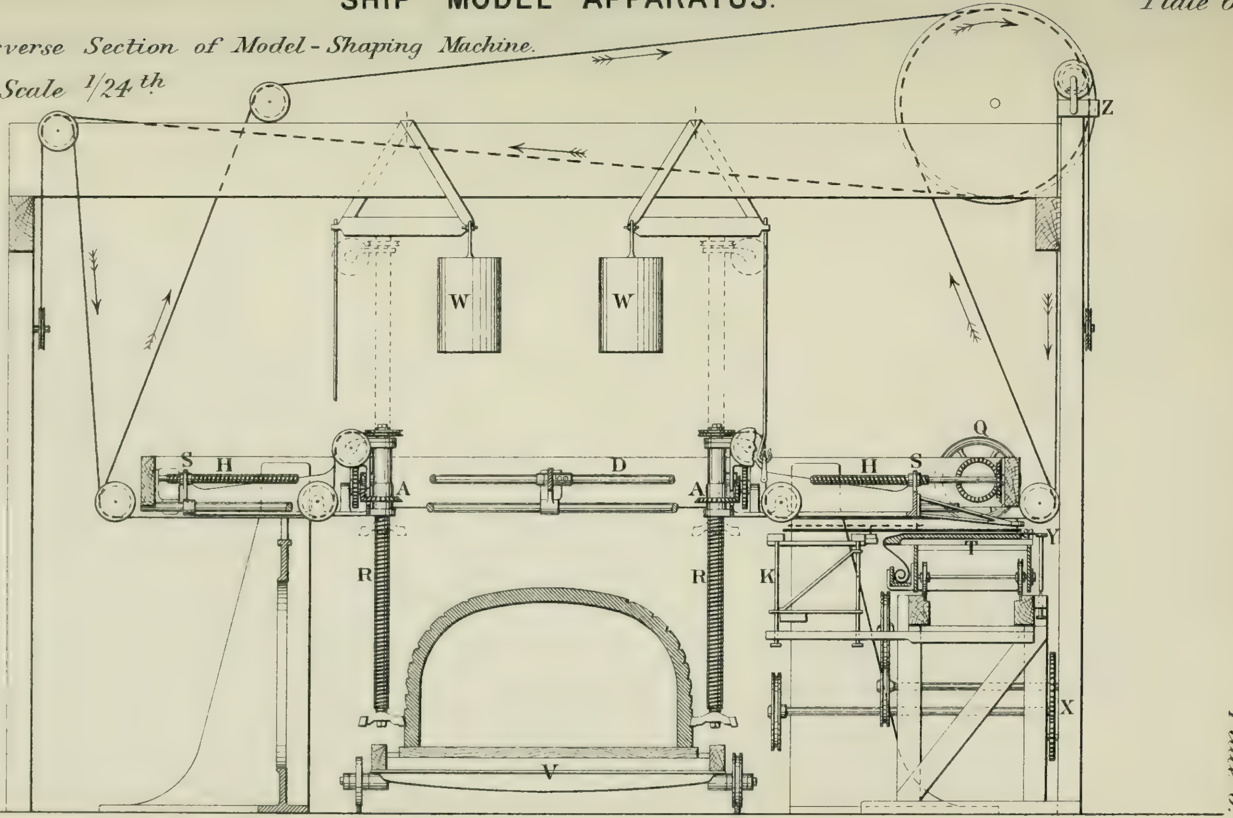
Scale 1/3rd

Plate 5.

SHIP MODEL APPARATUS.

Fig. 15. *Transverse Section of Model-Shaping Machine.*

Scale 1/24th.



Mechanical Engineers 1893.

Plate 6.

SHIP MODEL APPARATUS.

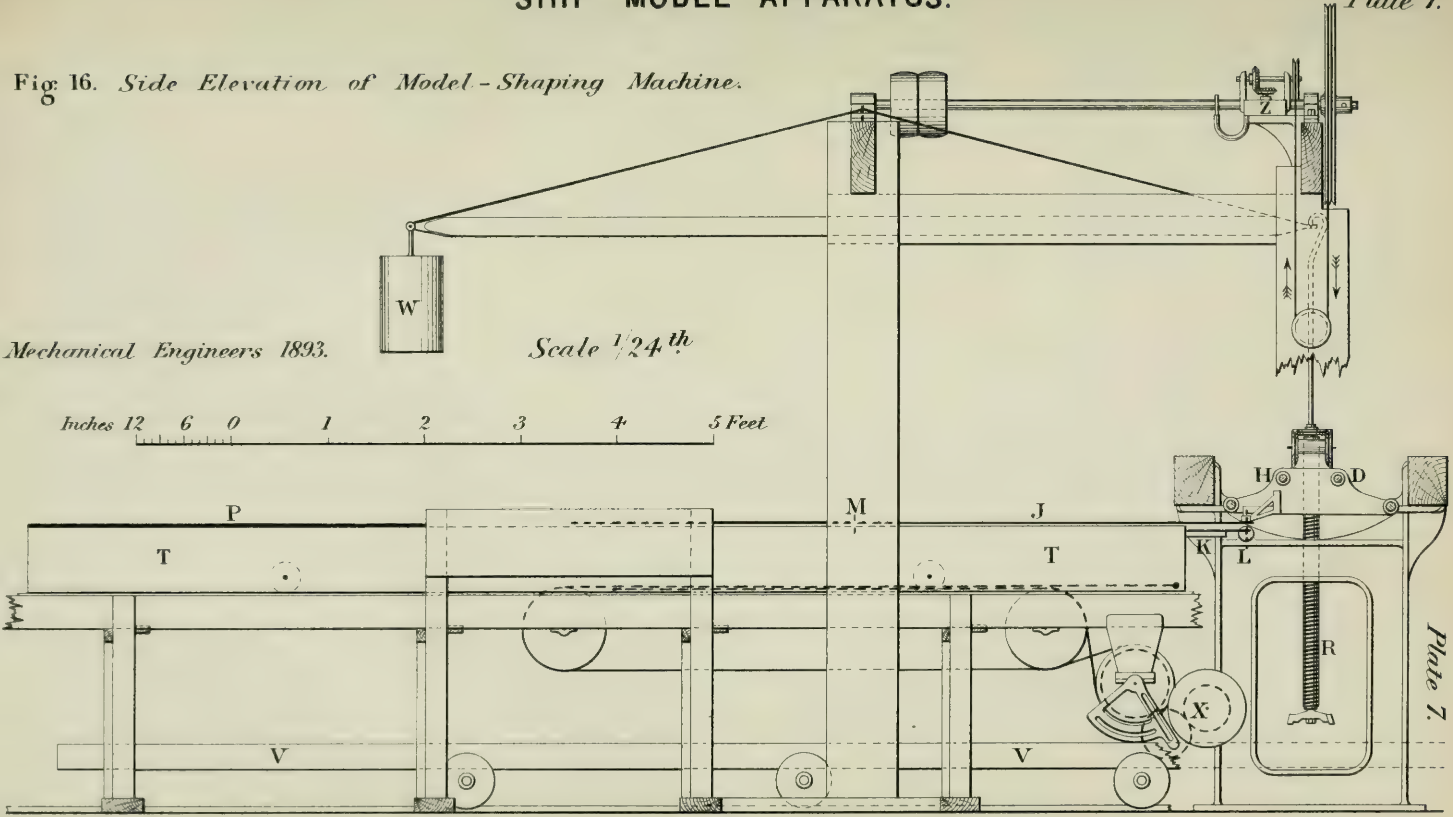


Fig. 16. *Side Elevation of Model-Shaping Machine.*

Mechanical Engineers 1893.

Scale 1/24th.

Plate 7.

SHIP MODEL APPARATUS.

Plate 8.

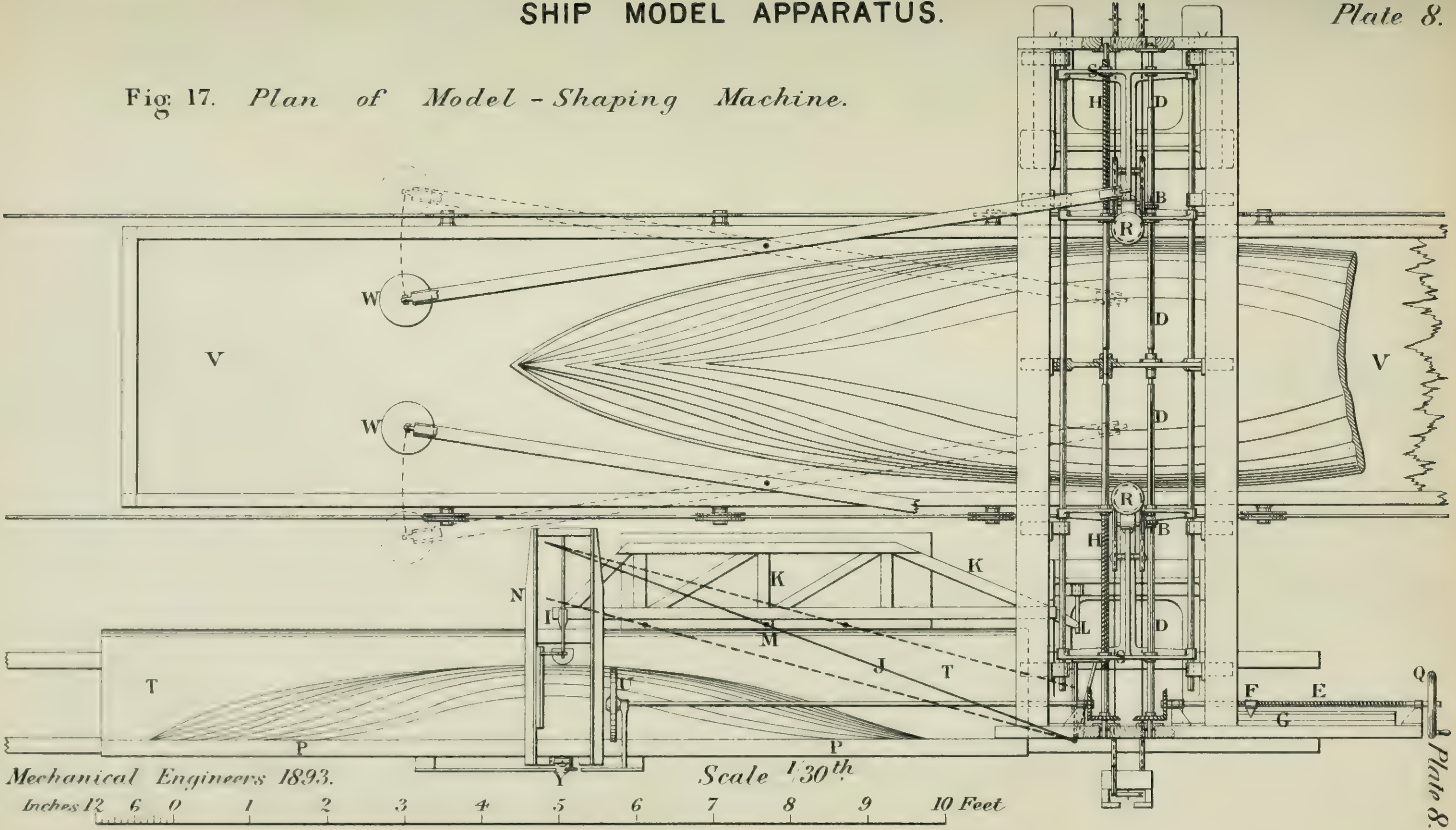


Fig. 17. *Plan of Model-Shaping Machine.*

Scale 1/30th.

Mechanical Engineers 1893.

SHIP MODEL APPARATUS.

Model-Shaping Machine.

Fig. 19. *Plan of Cutters.*

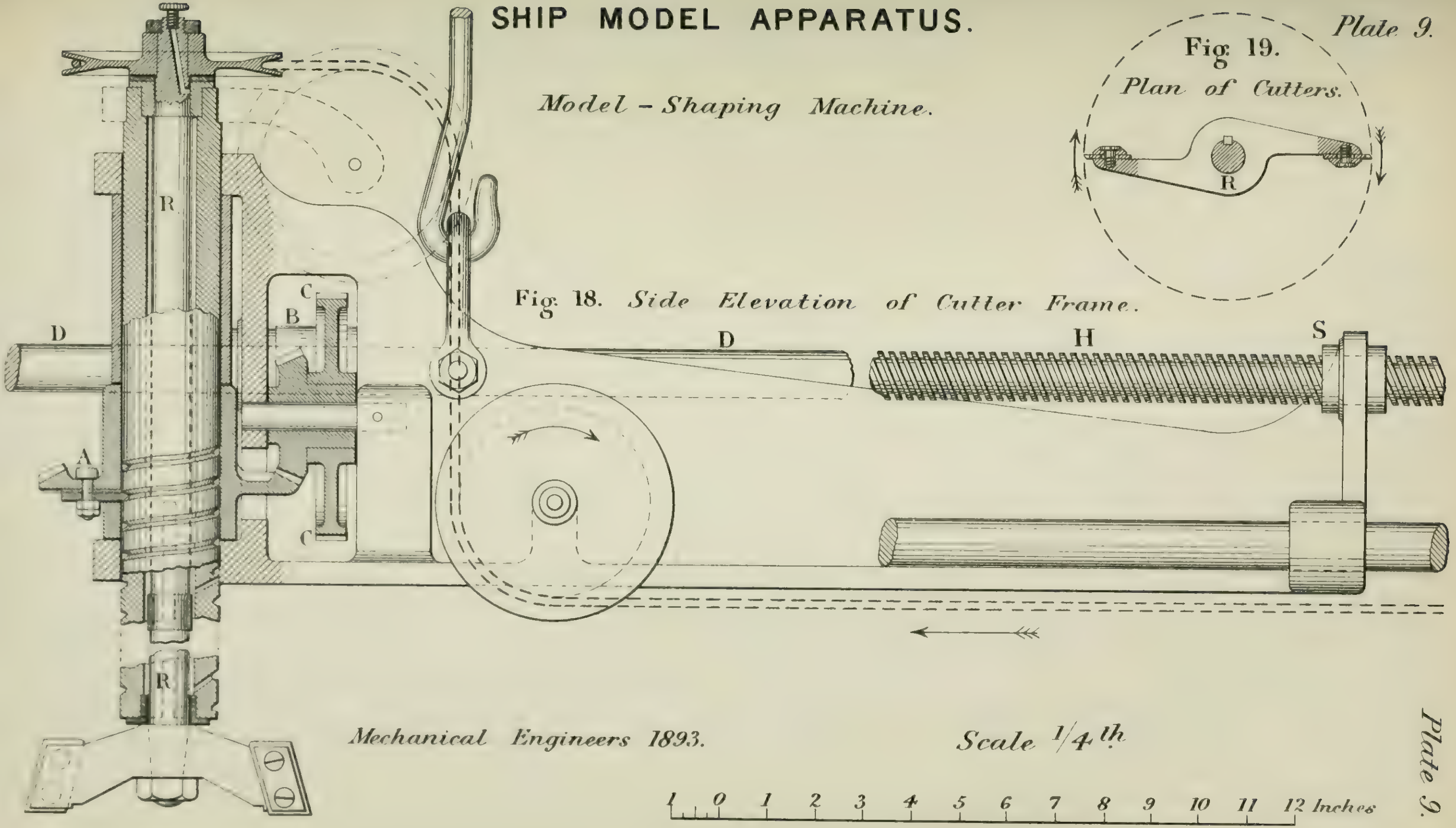
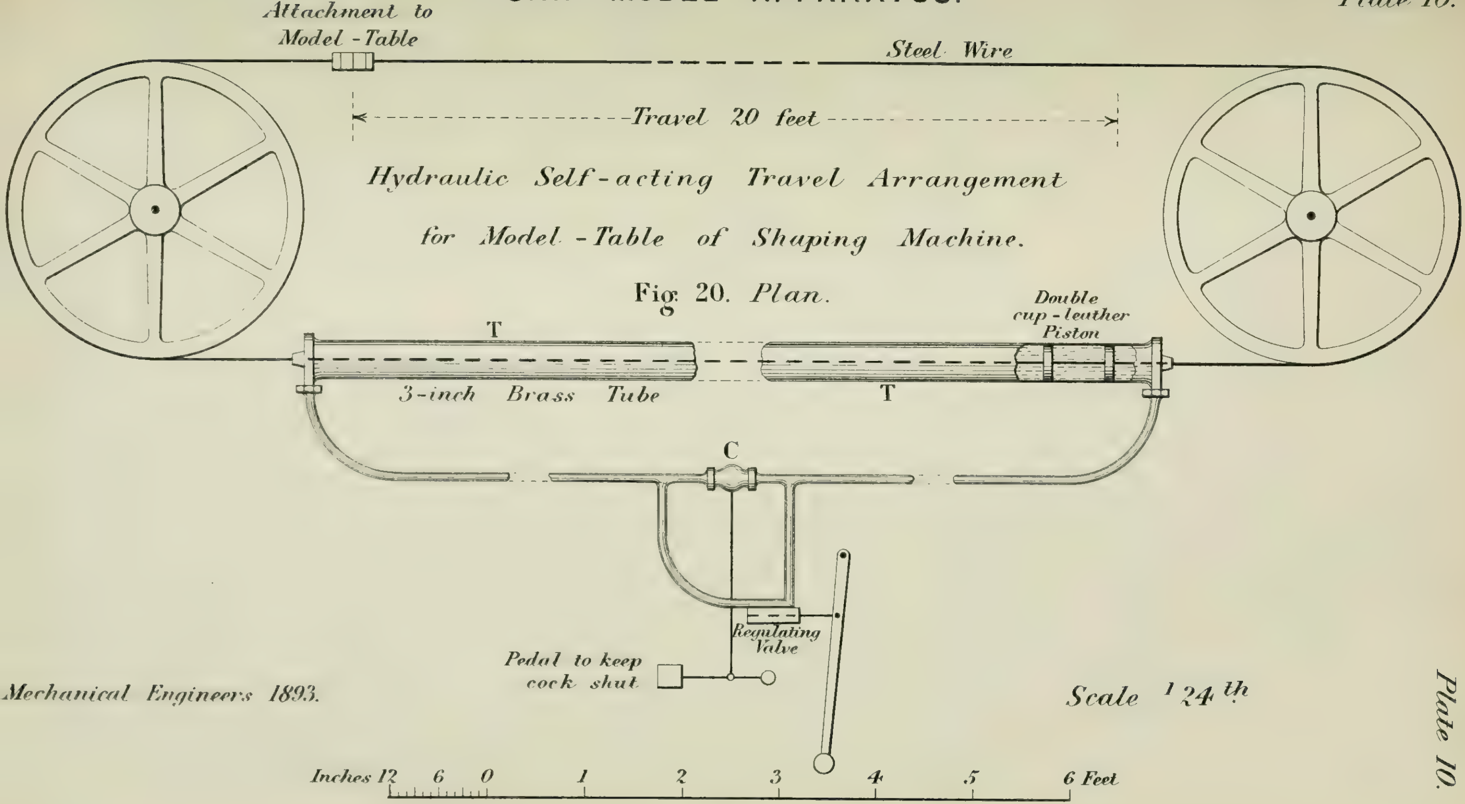


Fig. 18. *Side Elevation of Cutter Frame.*

Mechanical Engineers 1893.

Scale 1/4th.

SHIP MODEL APPARATUS.



Hydraulic Self-acting Travel Arrangement for Model-Table of Shaping Machine.

Fig. 20. Plan.

Weighing Machine.

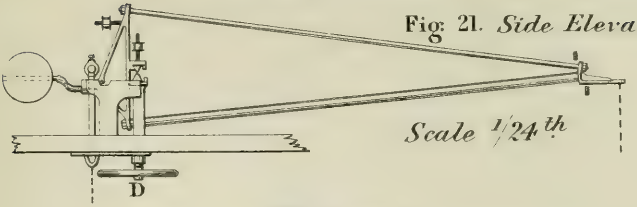


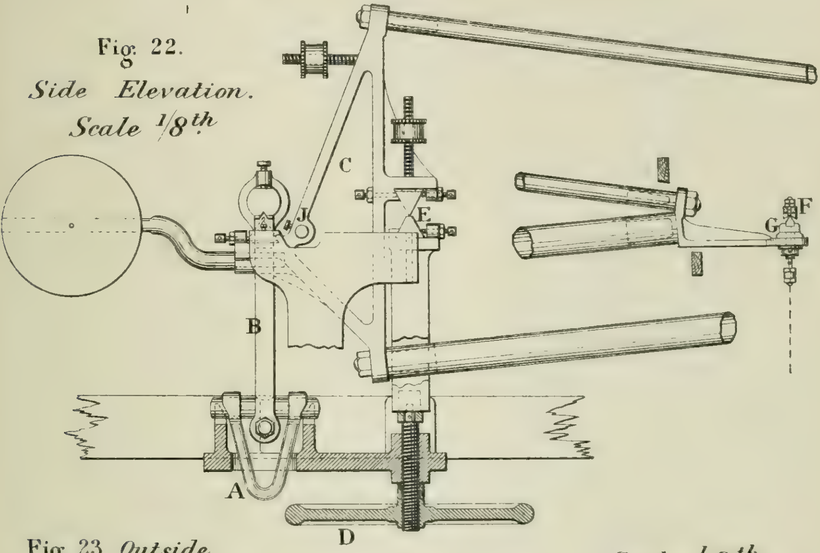
Fig: 21. *Side Elevation.*

Scale 1/24th.

Fig: 22.

Side Elevation.

Scale 1/8th.



Scale 1/8th.

Fig: 23. *Outside End Elevation.*

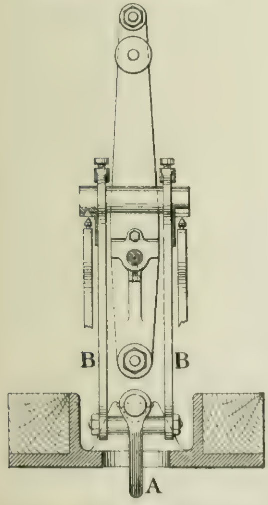


Fig: 24. *Inside End Elevation.*

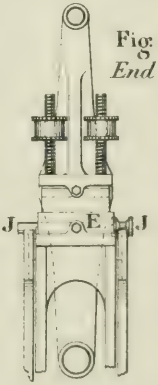
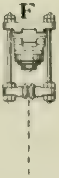
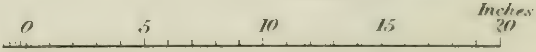


Fig: 25. *End Elevation at Weight end.*



Scale 1/8th.



SOUTHAMPTON WATER WORKS.

Plate 12.

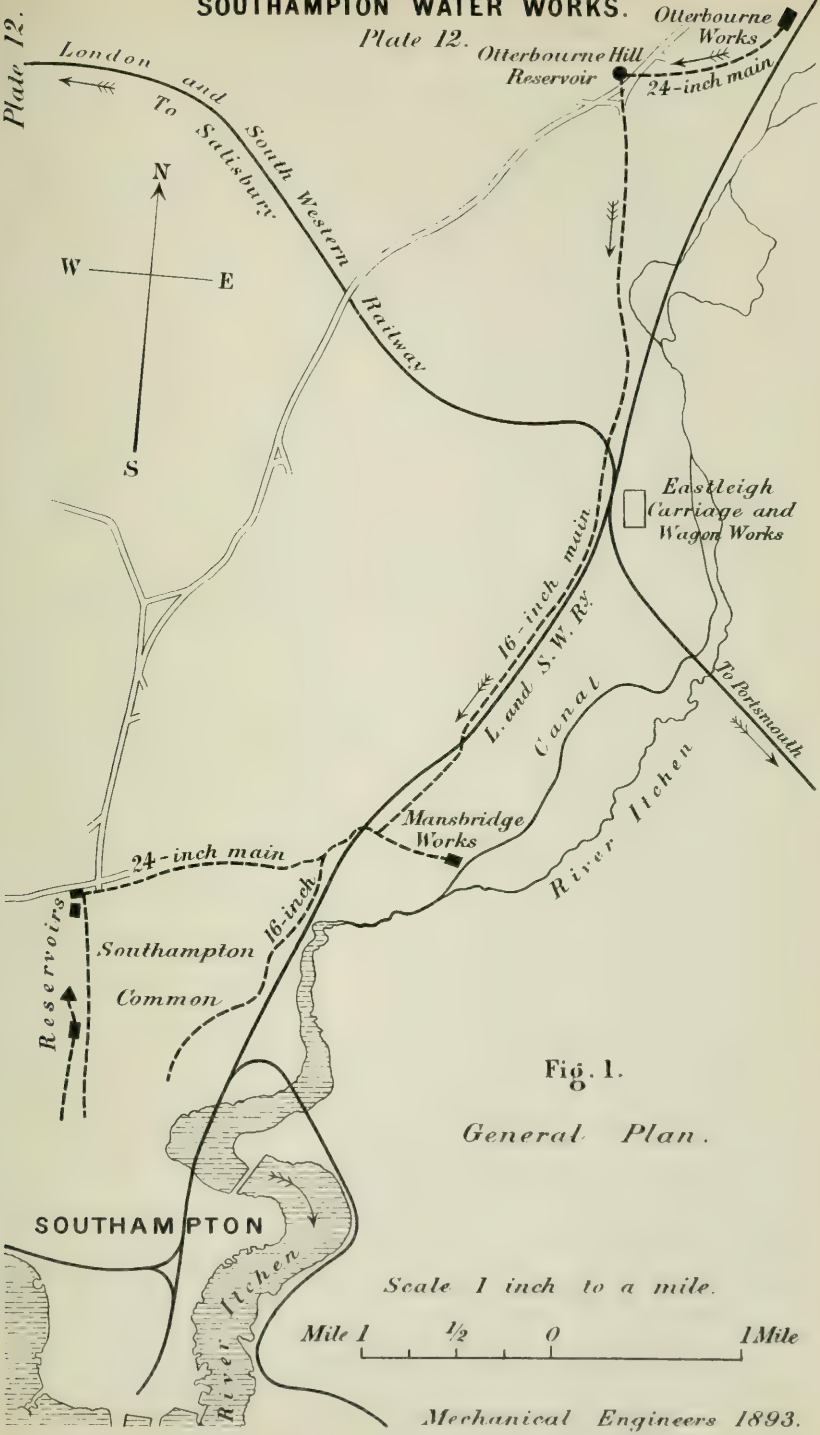


Fig. 1.

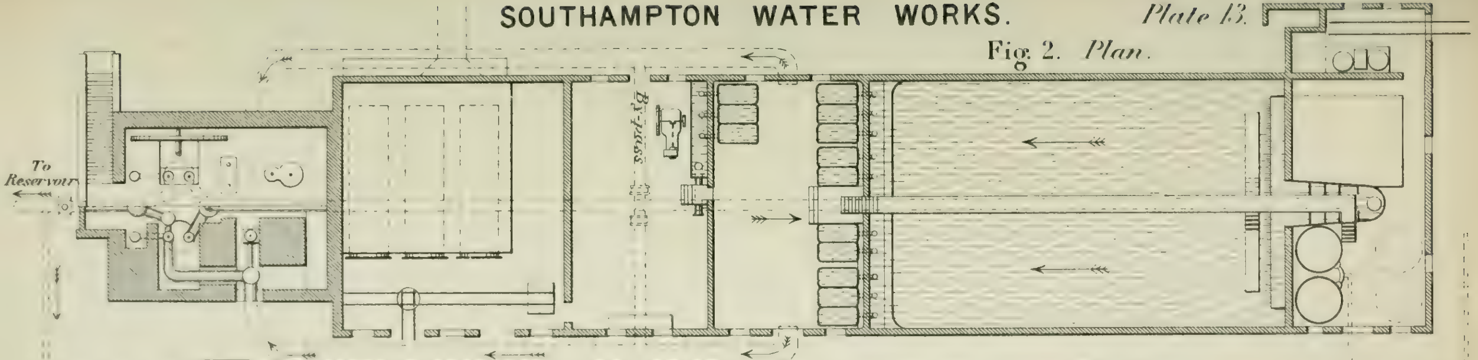
General Plan.

Scale 1 inch to a mile.

SOUTHAMPTON WATER WORKS.

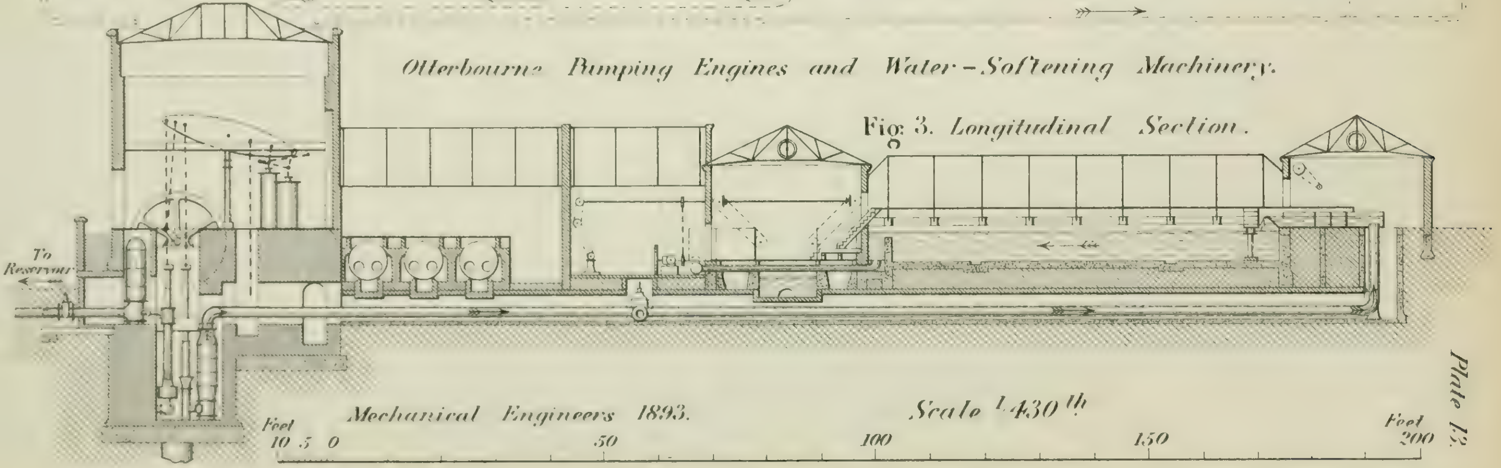
Plate 13.

Fig. 2. *Plan.*



Otterbourne Pumping Engines and Water-Softening Machinery.

Fig. 3. *Longitudinal Section.*



Mechanical Engineers 1893.

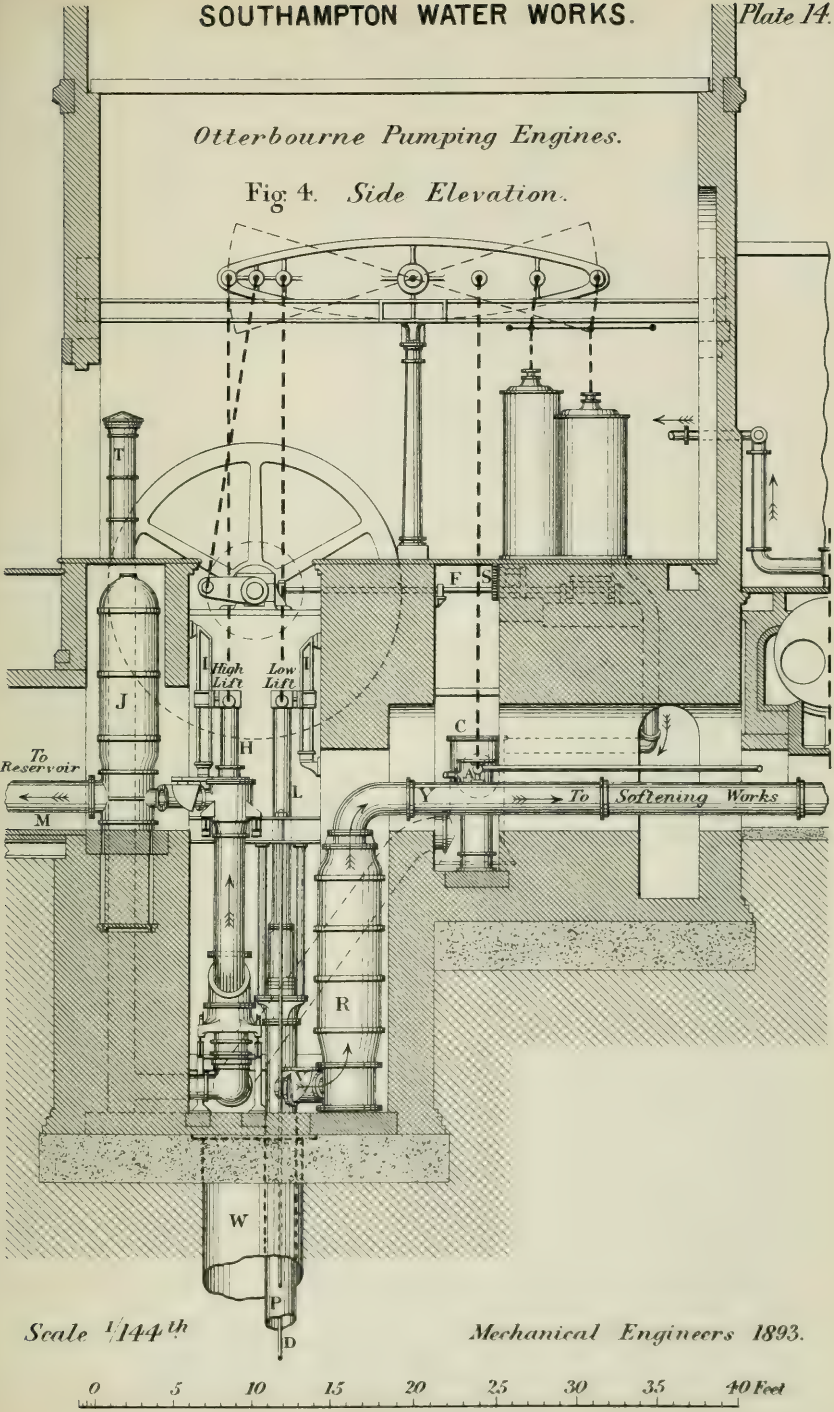
Scale 1/430th

Plate 13.

SOUTHAMPTON WATER WORKS.

Otterbourne Pumping Engines.

Fig. 4. *Side Elevation.*



Scale 1/144th.

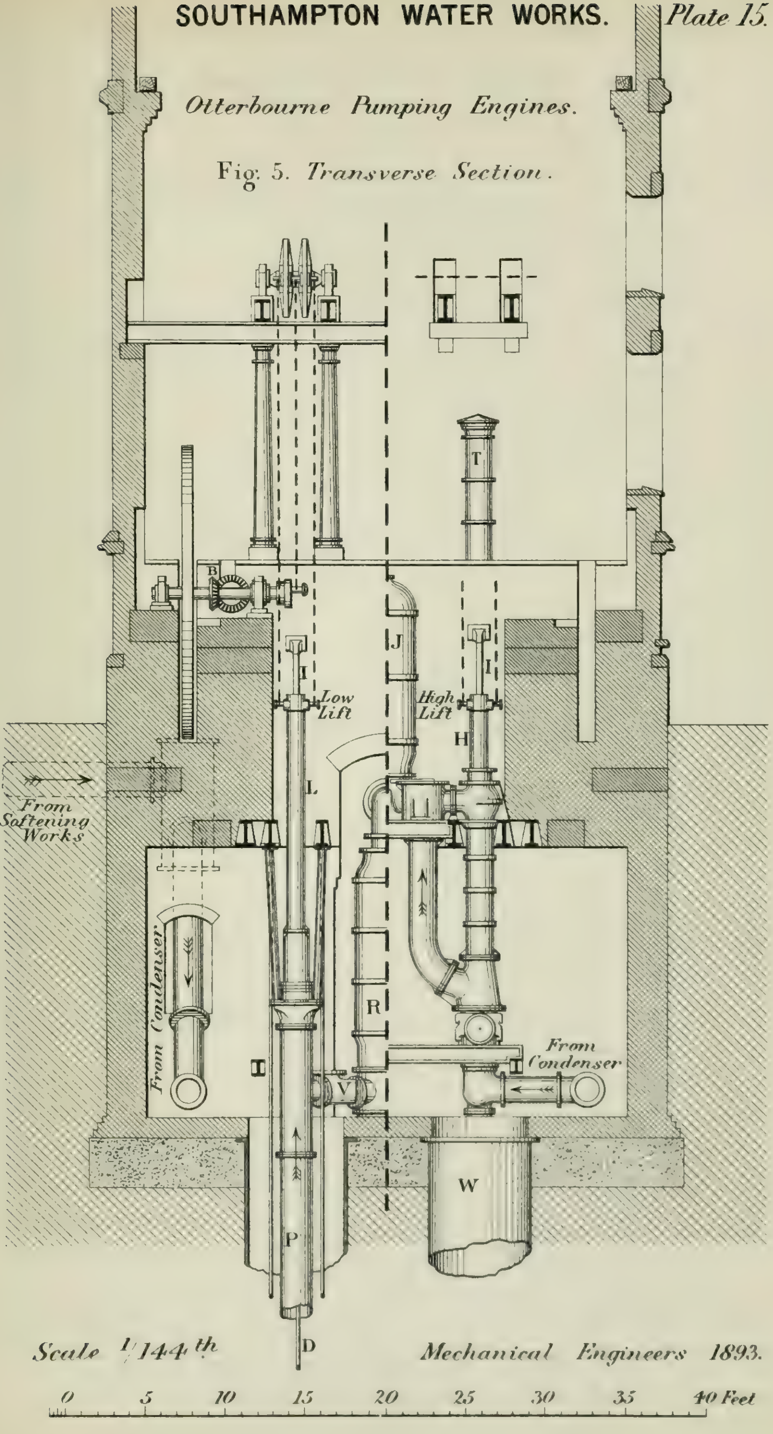
Mechanical Engineers 1893.

SOUTHAMPTON WATER WORKS.

Plate 15.

Otterbourne Pumping Engines.

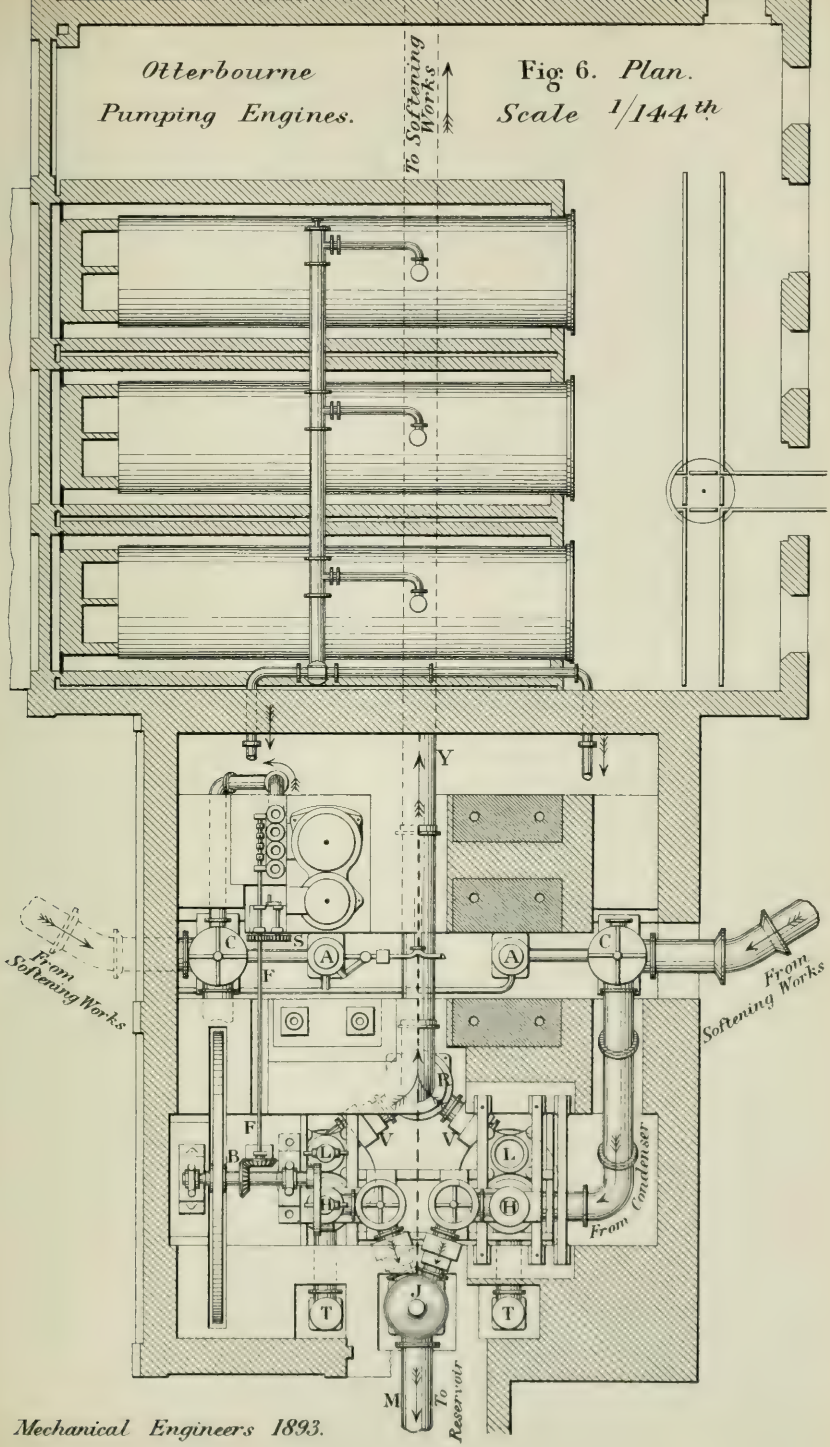
Fig. 5. *Transverse Section.*



Scale $^1/_{144}{}^{th}$.

Mechanical Engineers 1893.

SOUTHAMPTON WATER WORKS.



Otterbourne Pumping Engines.

Fig. 6. Plan. Scale 1/144th

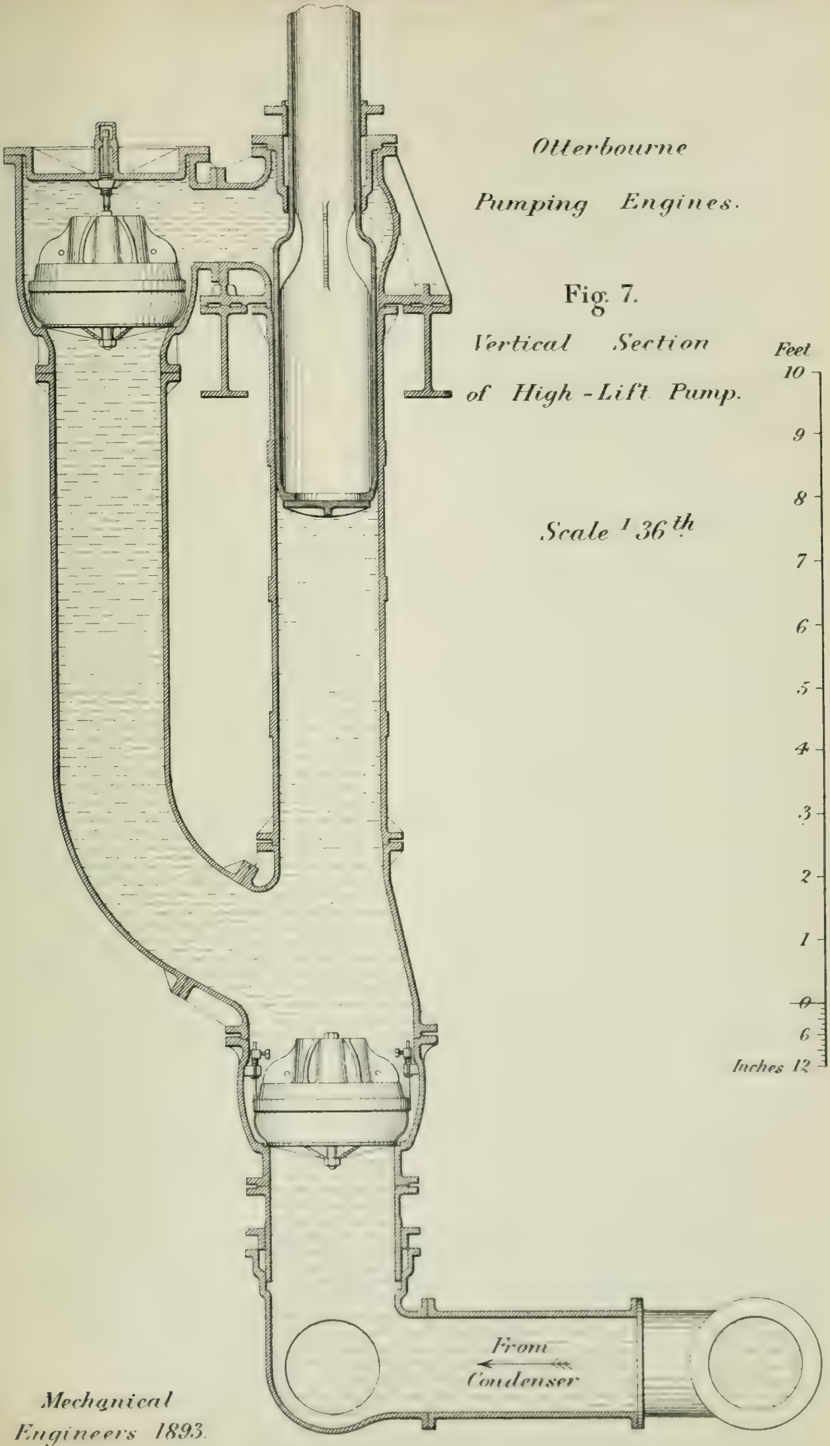
Otterbourne

Pumping Engines.

Fig. 7.

Vertical Section of High-Lift Pump.

Scale 1/36th.

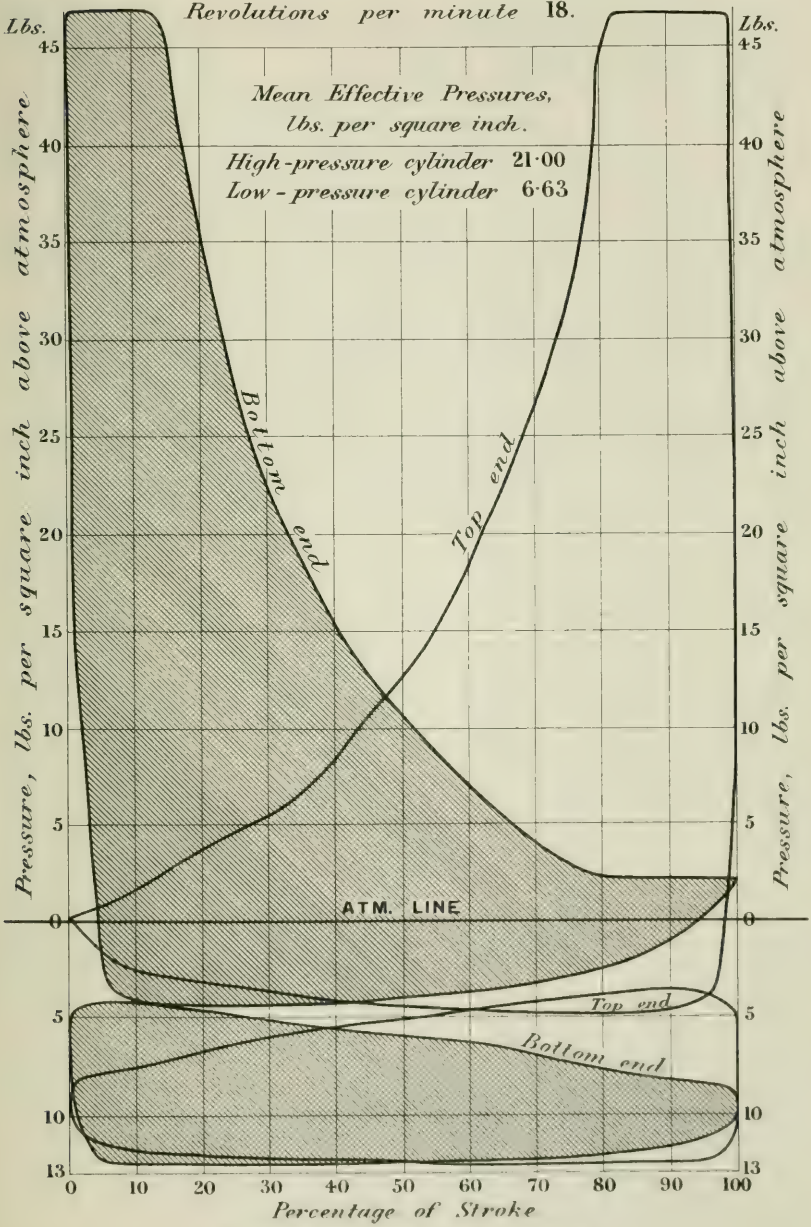


Mechanical Engineers 1893.

Fig. 8. *Indicator Diagrams from Otterbourne Compound Rotative Beam Engines.*

Boiler Pressure 60 *lbs. per sq. inch above atm.*

Revolutions per minute 18.



Mean Effective Pressures, lbs. per square inch.

High-pressure cylinder 21·00
Low-pressure cylinder 6·63

SOUTHAMPTON WATER WORKS. *Plate 19.*

Fig. 9. *Indicator Diagrams from Mansbridge Single-Acting Cornish Beam Engine. Strokes per minute* 10.

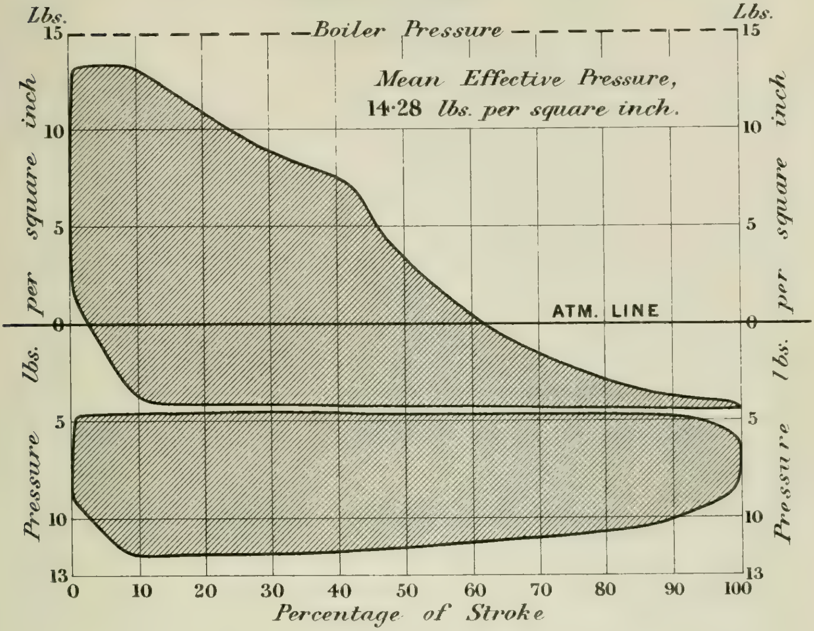
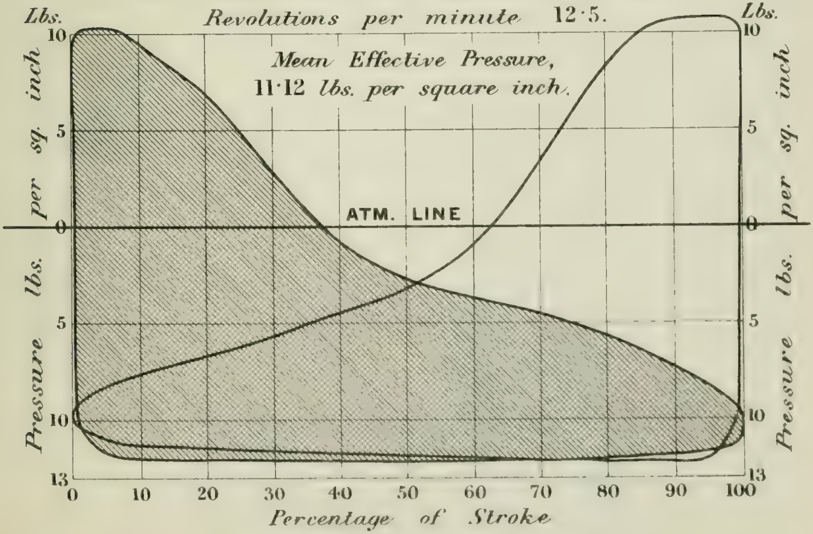


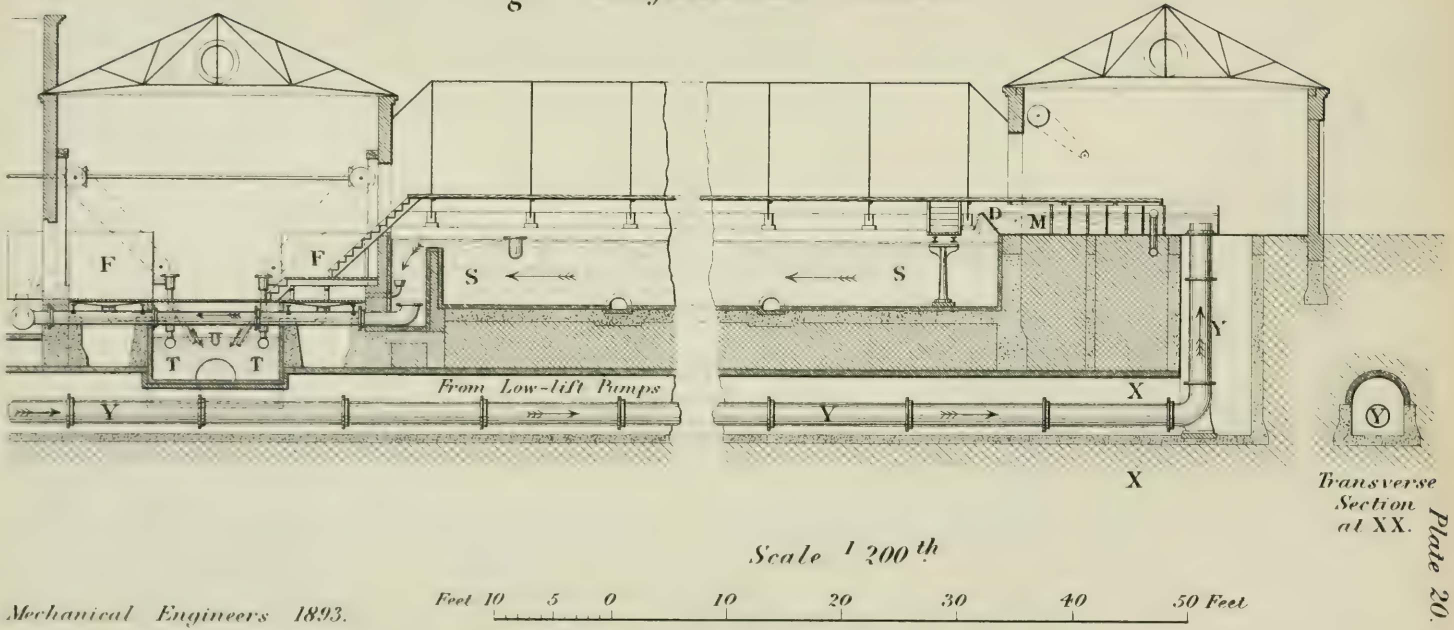
Fig. 10. *Indicator Diagrams from Mansbridge Rotative Beam Engine. Boiler Pressure* 20 *lbs. per sq. inch above atm. Revolutions per minute* 12·5.



SOUTHAMPTON WATER WORKS.

Water-Softening Machinery.

Fig: 11. *Longitudinal Section.*



Transverse Section at XX.

Scale 1/200th

SOUTHAMPTON WATER WORKS.

Water - Softening Machinery. Fig: 12. Plan.

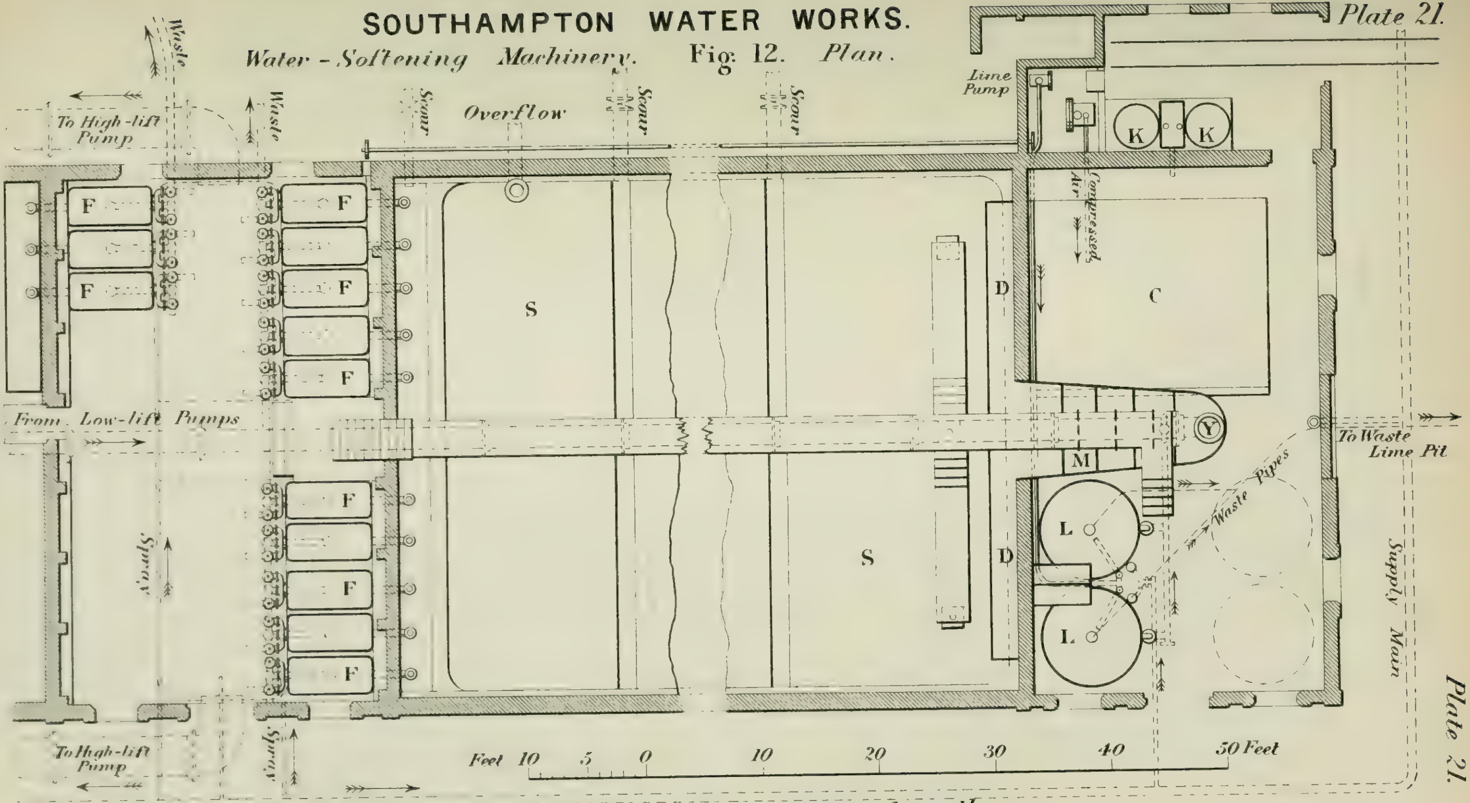


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Plate 21.

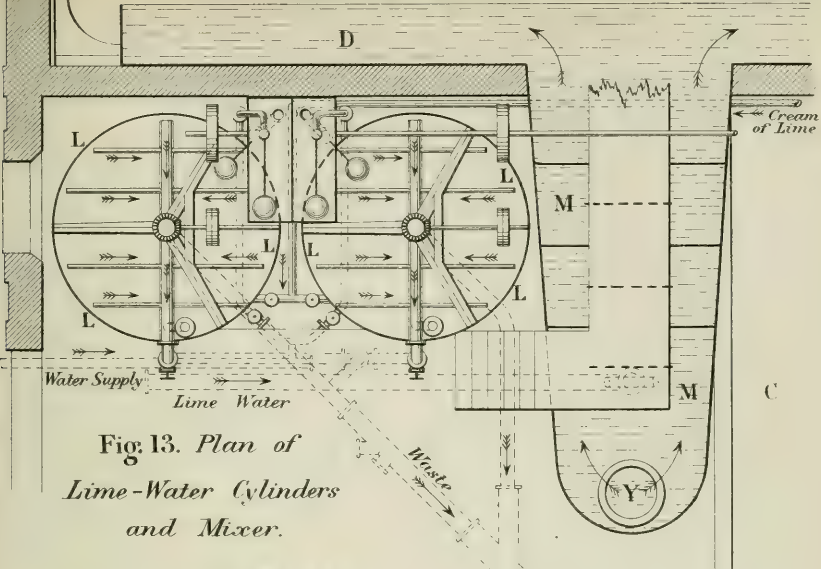


Fig. 13. *Plan of Lime-Water Cylinders and Mixer.*

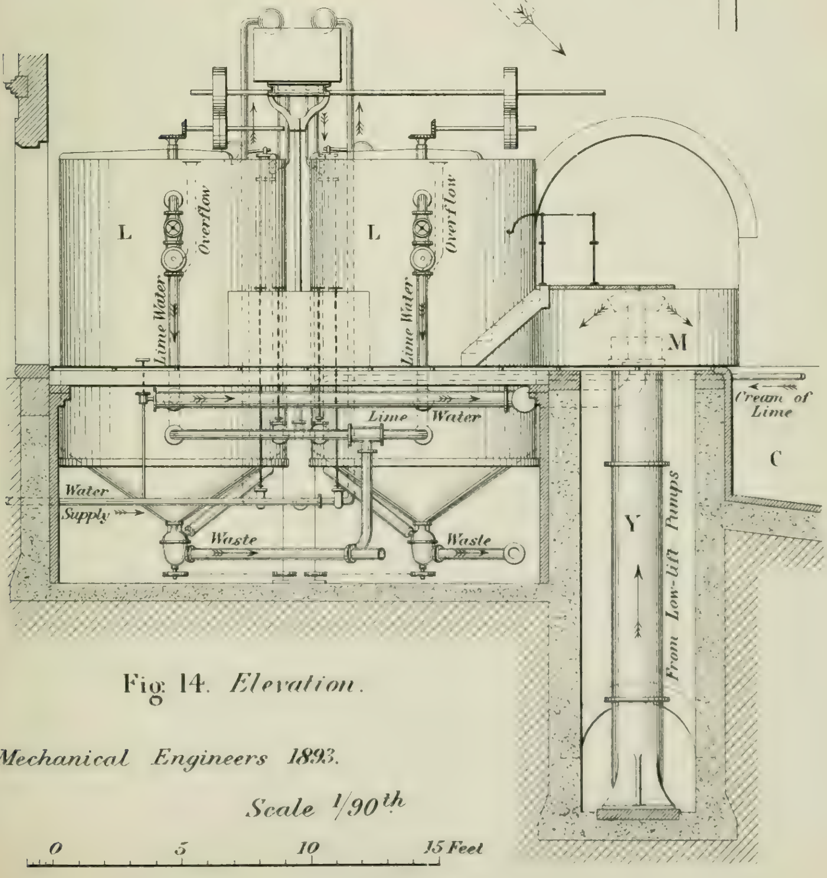


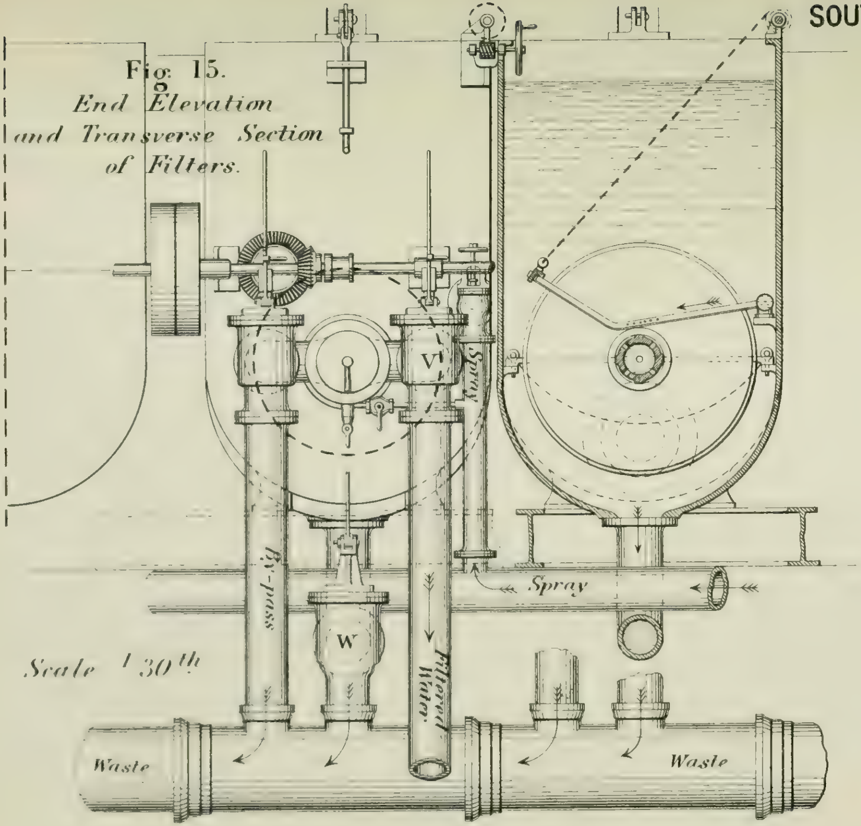
Fig. 14. *Elevation.*

Scale $1/90^{th}$

0 5 10 15 Feet

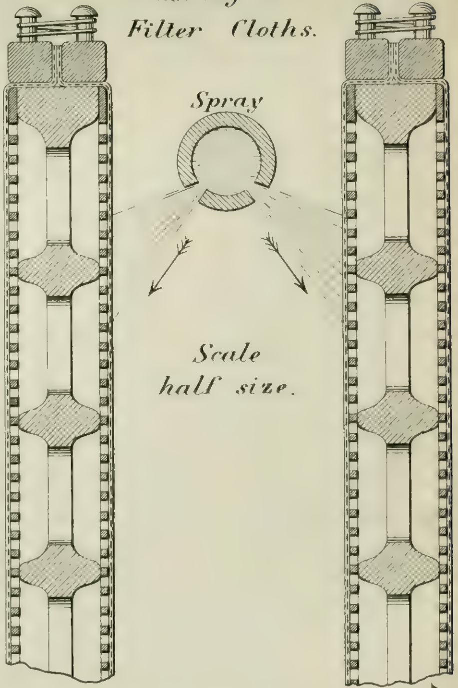
SOUTHAMPTON WATER WORKS.

Fig. 15.
End Elevation
and Transverse Section
of Filters.



Scale 1/30th.

Fig. 16.
Washing of
Filter Cloths.



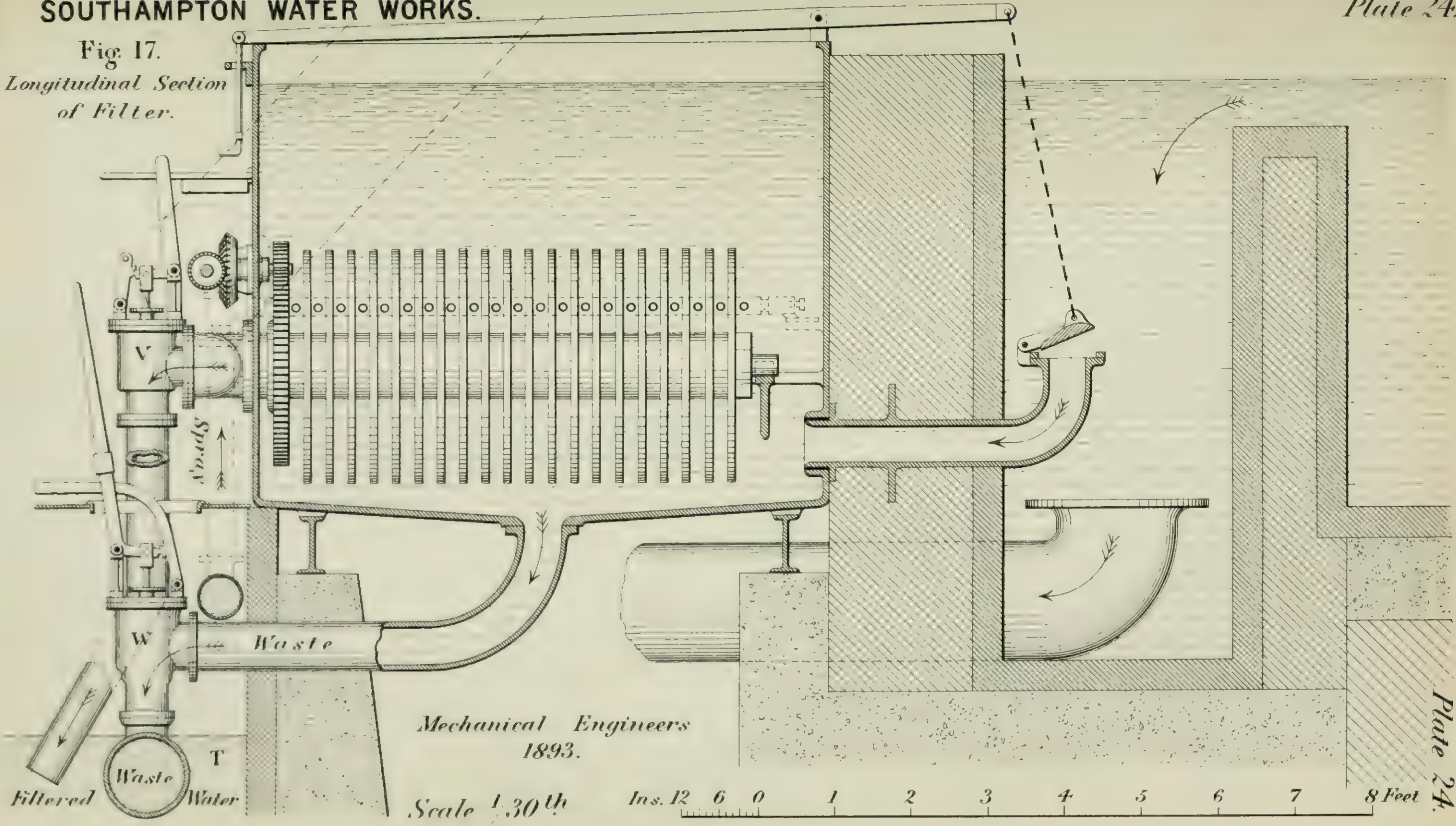
Scale
half size.

Pl. 23.

SOUTHAMPTON WATER WORKS.

Fig. 17.

Longitudinal Section of Filter.

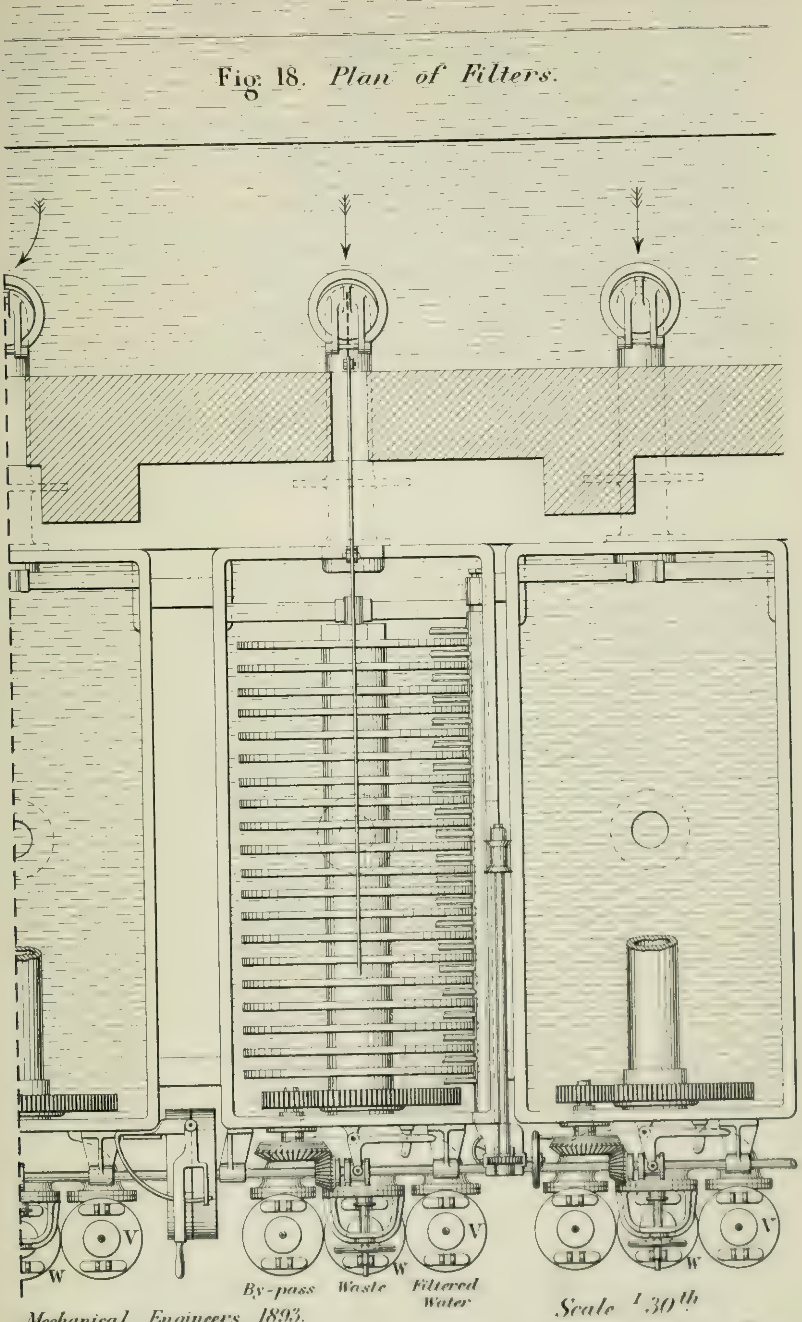


Mechanical Engineers 1893.

Scale 1/30th

Plate 24.

Fig. 18. *Plan of Filters.*



SOUTHAMPTON WATER WORKS. *Plate 26.*

Fig: 19. *Sectional Plan of Filter Discs.*

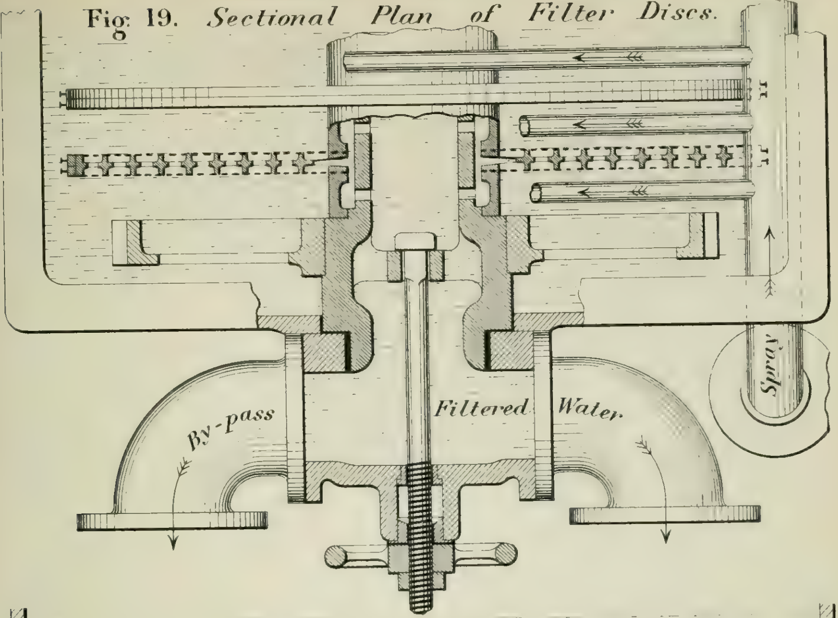
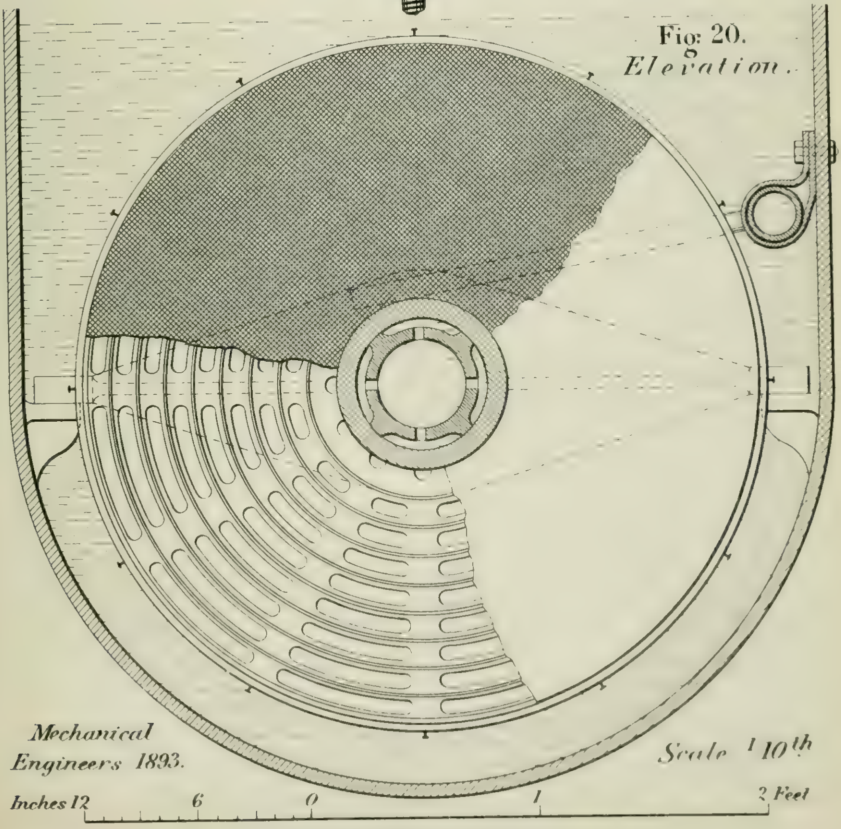


Fig: 20. *Elevation.*



Mechanical Engineers 1893.

Scale 1/10th

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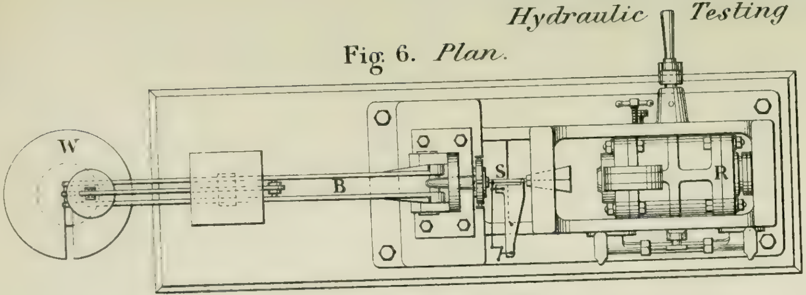
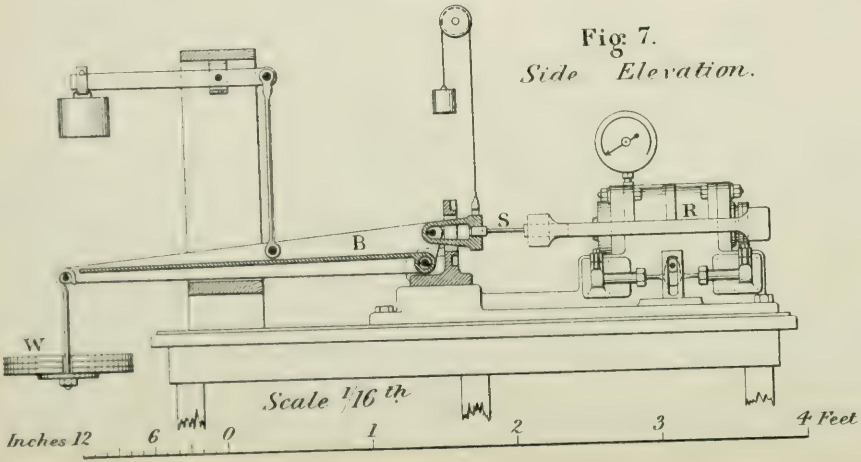
Hydraulic Testing Machine.

Fig. 6. *Plan.*



Scale 1/16th.

Fig. 7. *Side Elevation.*



Scale 1/16th.

Appliance for determining Limit of Elasticity.

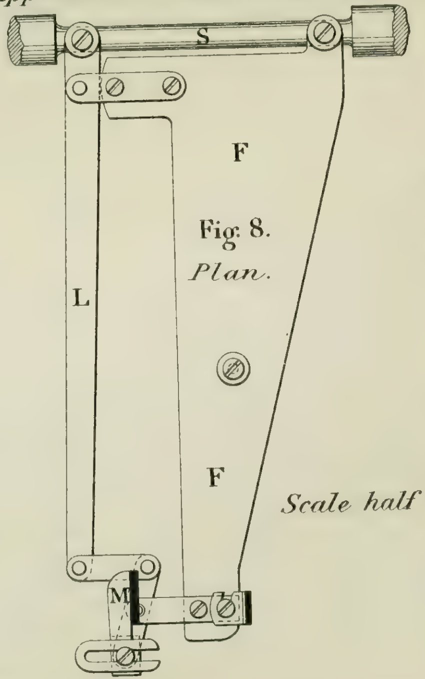


Fig. 8. *Plan.*

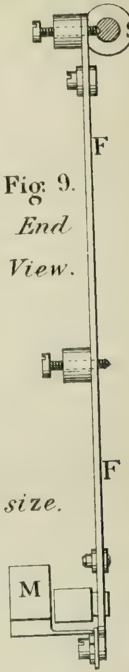


Fig. 9. *End View.*

Scale half size.

Plate 27.

ALLOYS RESEARCH.

Autographic Recording Pyrometer.

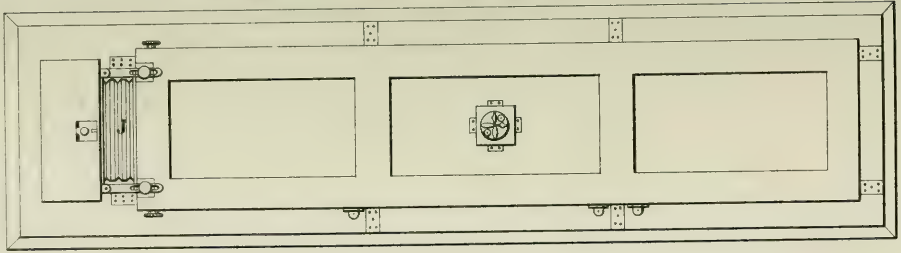


Fig. 10.

Plan.

Fig. 11.

Front Elevation.

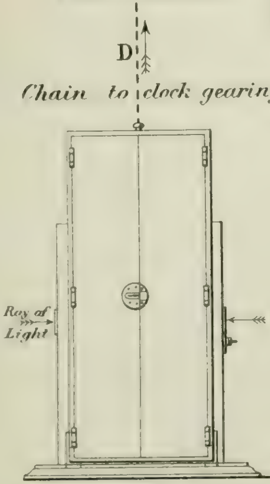


Fig. 12. Side Elevation.

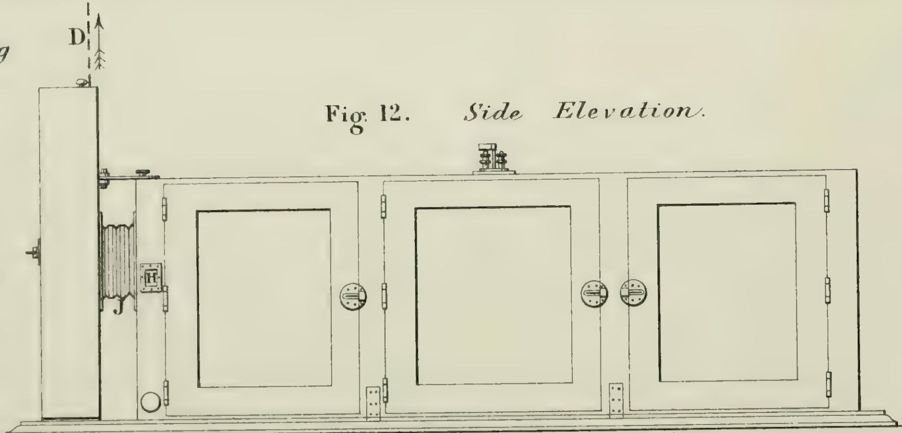
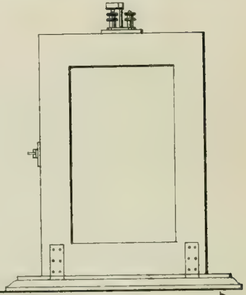


Fig. 13.

Back Elevation.



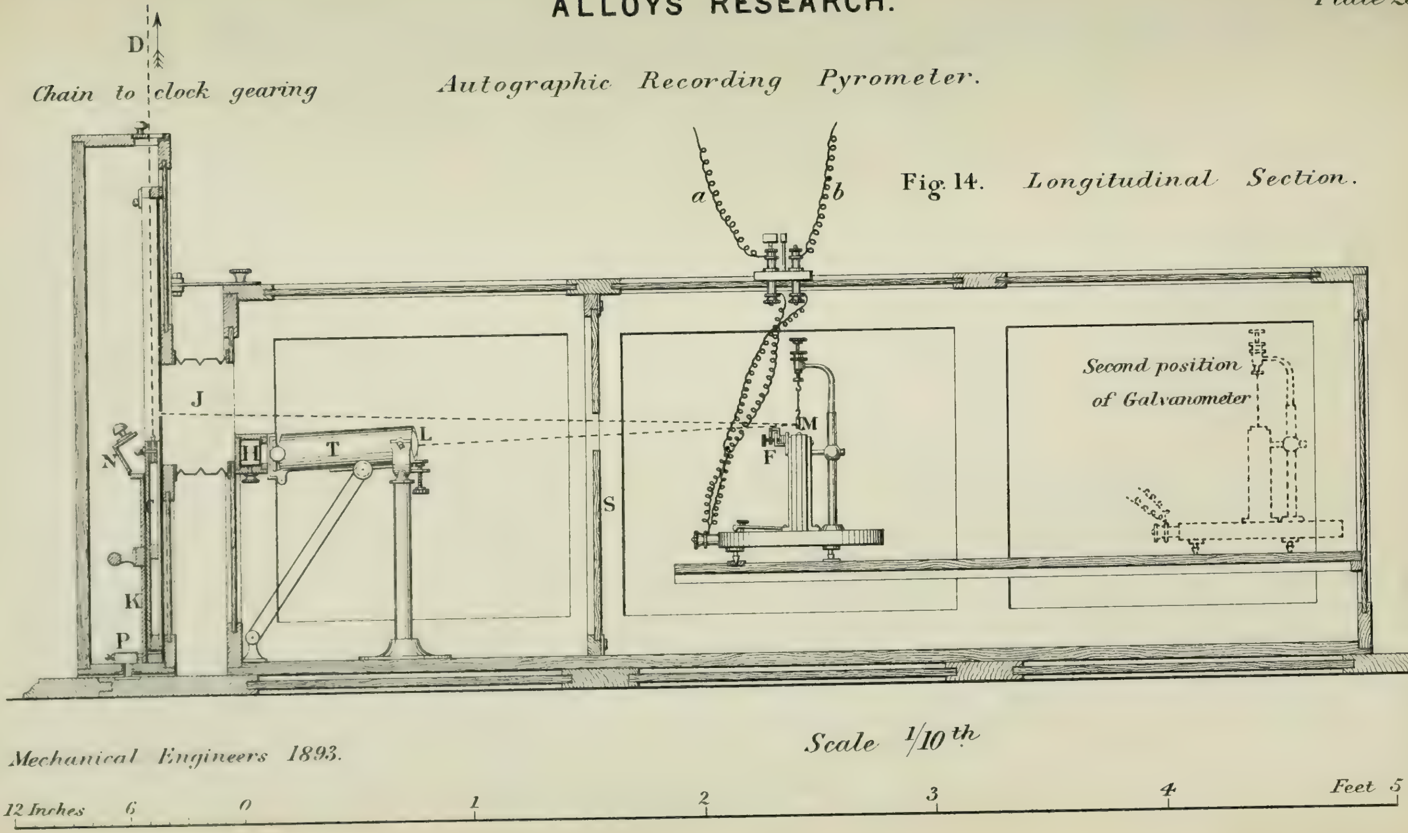
Scale 1/16th.

Inches 12 6 0 1 2 3 4 5 Feet

ALLOYS RESEARCH.

Autographic Recording Pyrometer.

Fig. 14. *Longitudinal Section.*



Scale 1/10th.

Plate 29.

Autographic Recording Pyrometer.

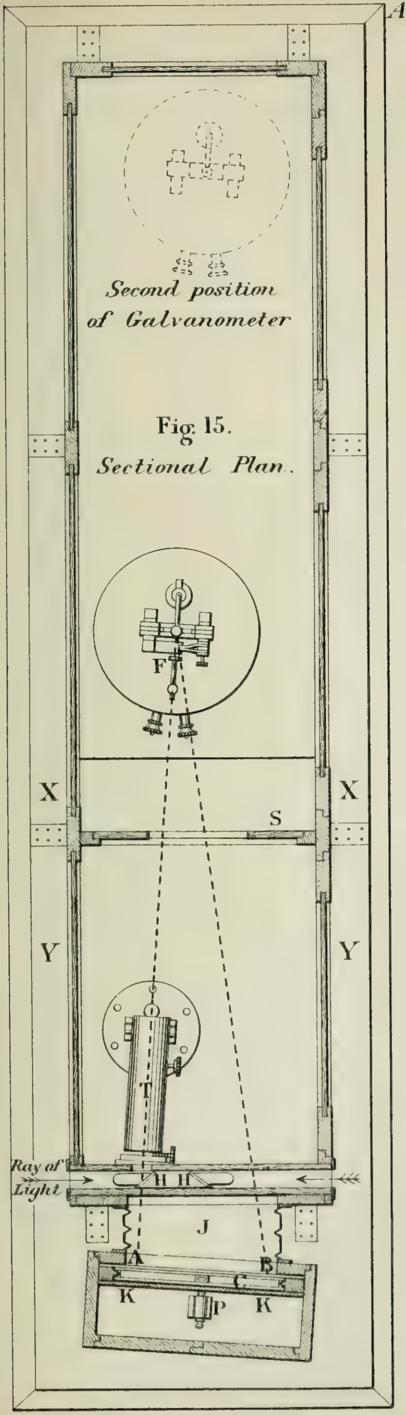


Fig. 15. *Sectional Plan.*

Fig. 16. *Transverse Section at XX, Fig. 15.*

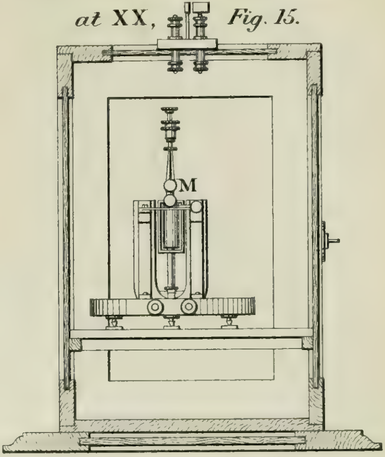
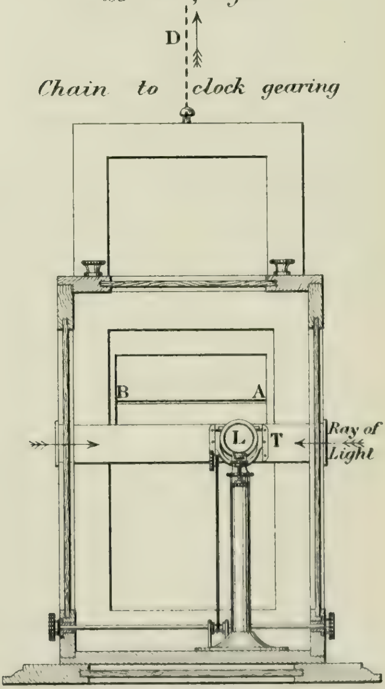


Fig. 17. *Transverse Section at YY, Fig. 15.*



Scale 1/10th.

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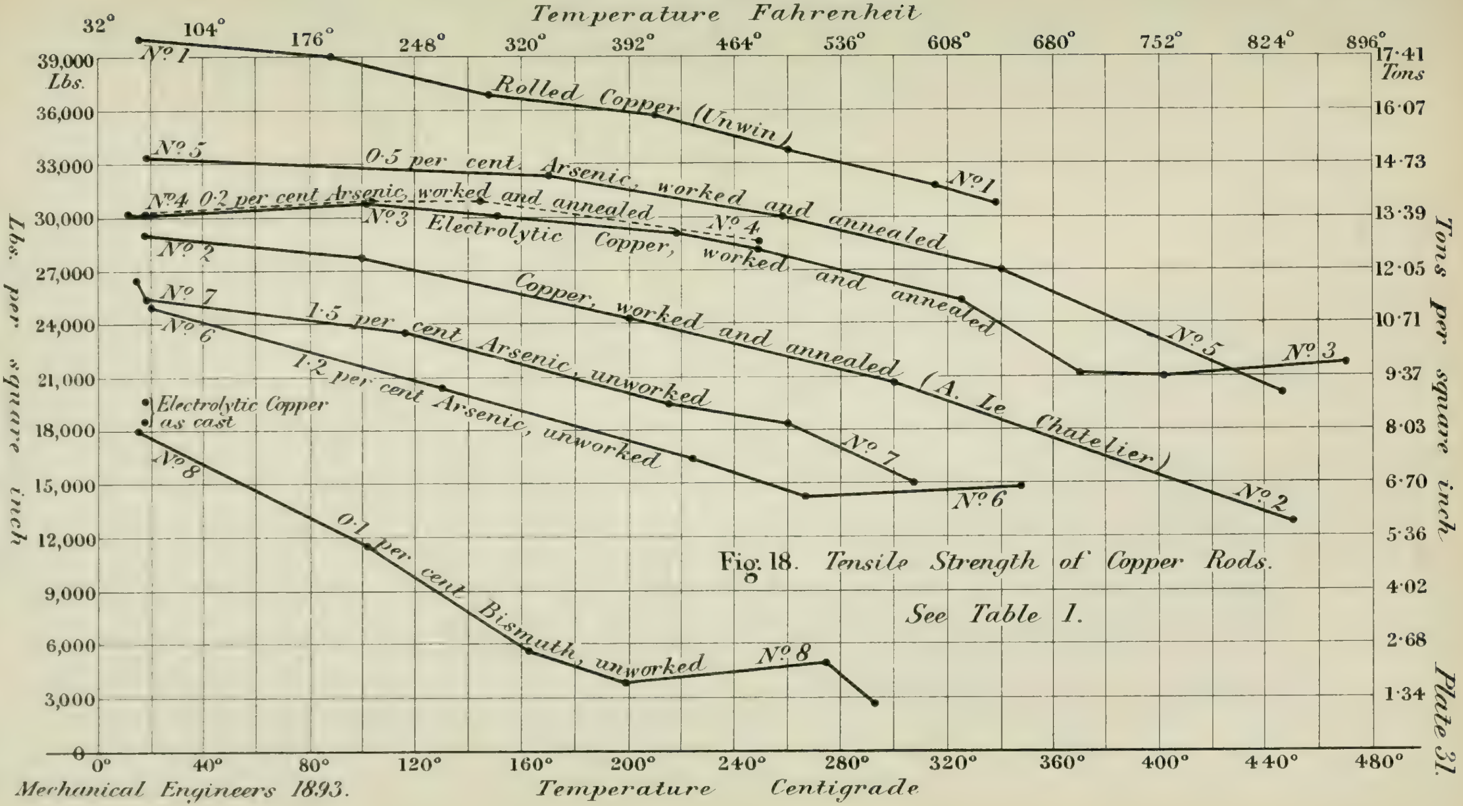

Fig. 18. *Tensile Strength of Copper Rods.*

See Table 1.

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Fig. 19. *Cooling of Copper-Bismuth Alloys.*

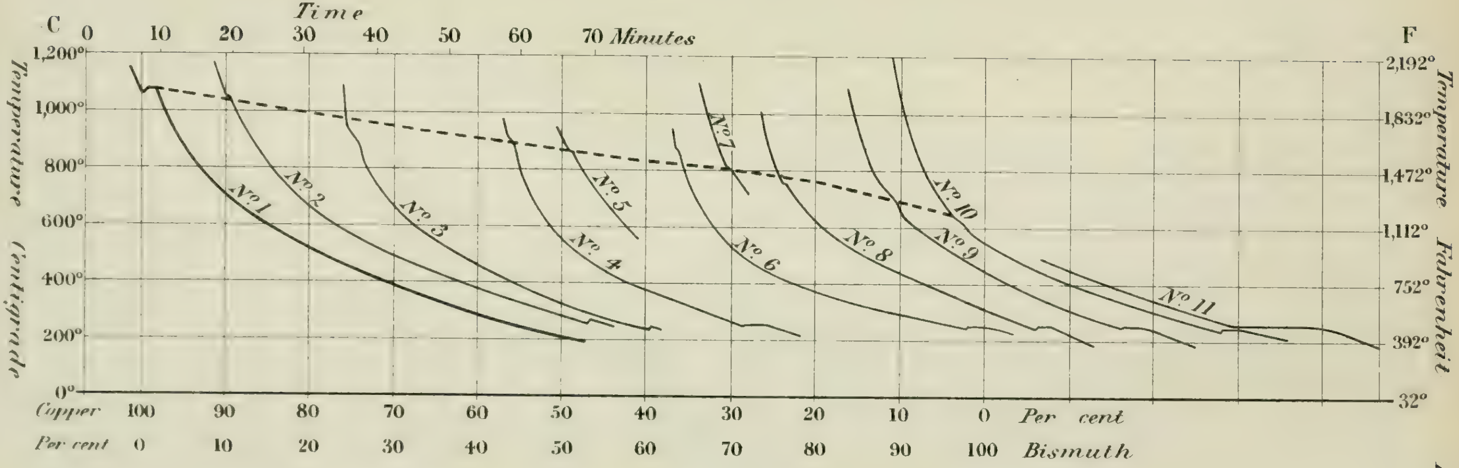

Fig. 20. *Effect of Pressure on Recalescence of Steel containing 0·9 per cent of Carbon.*

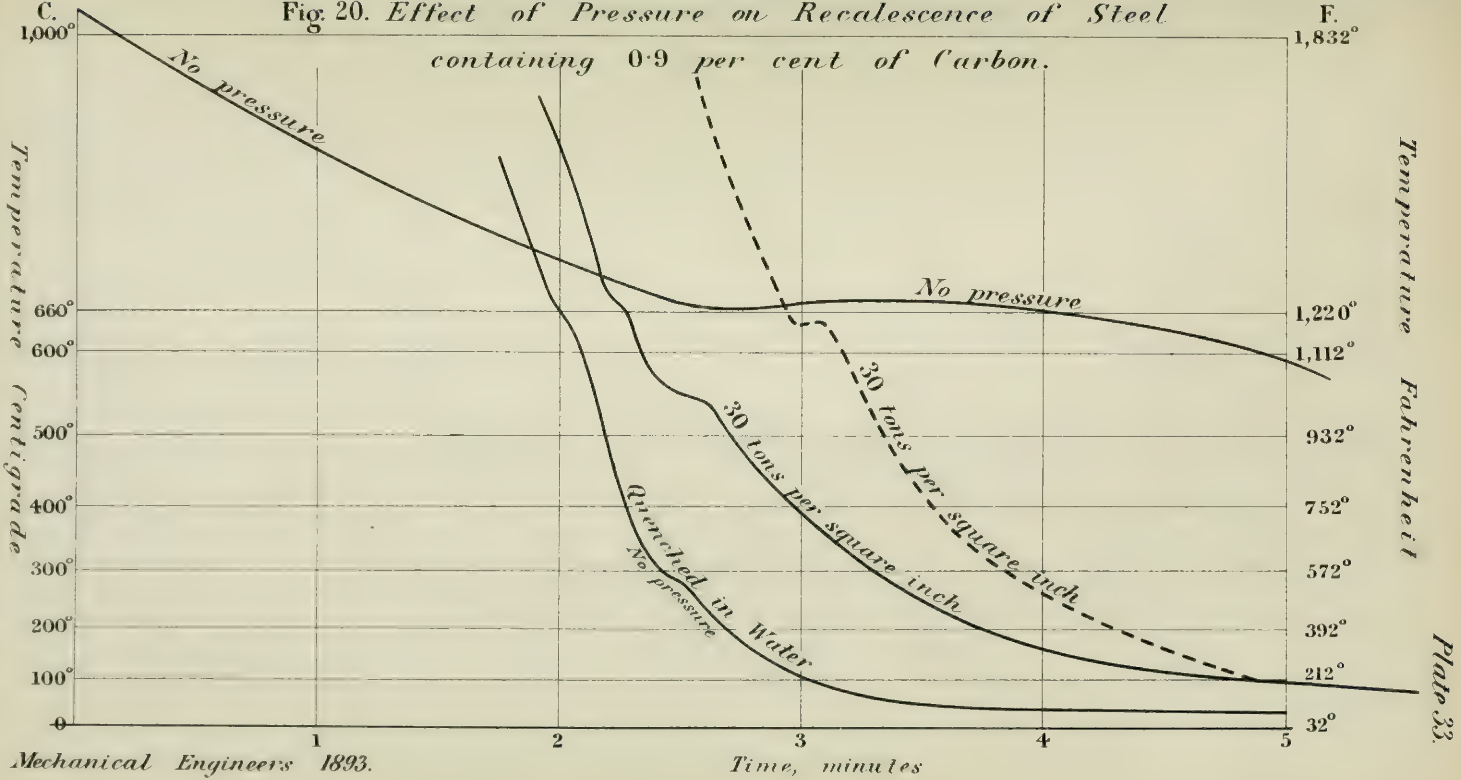

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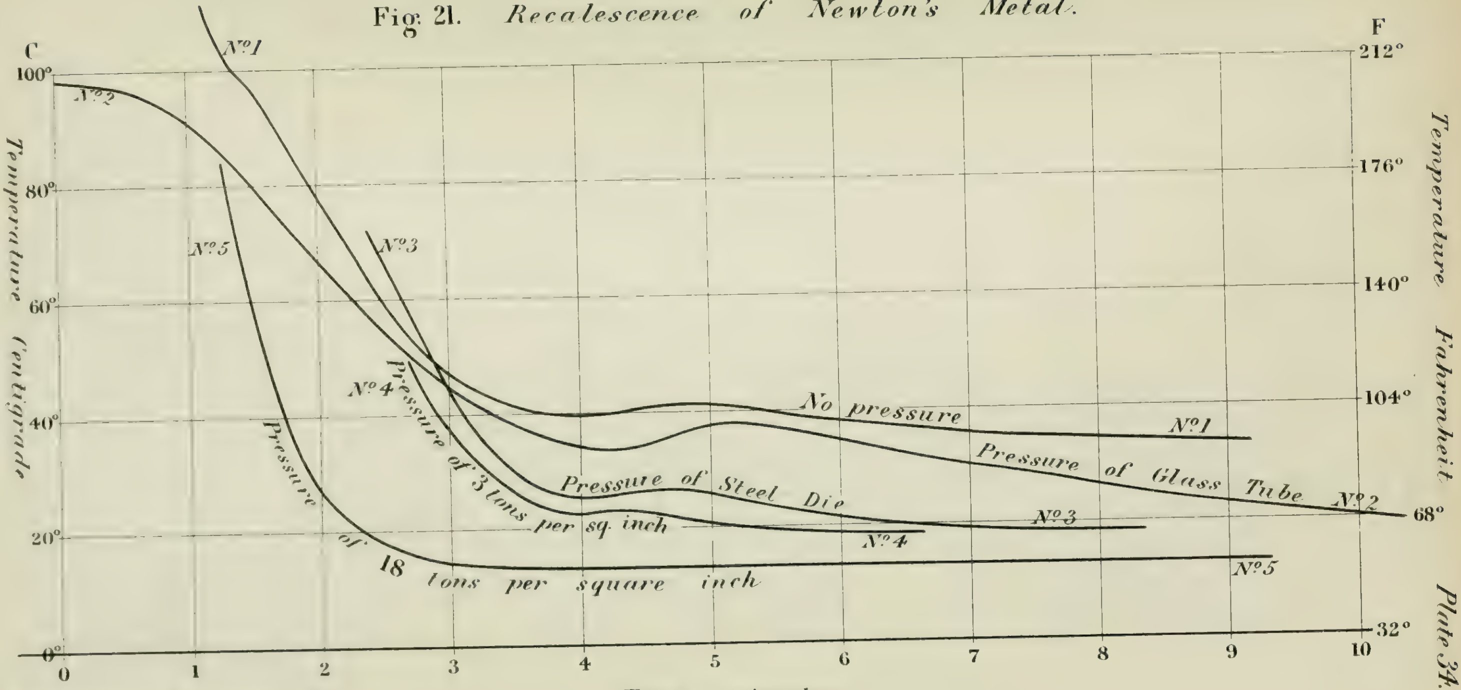
Fig. 21. *Recalescence of Newton's Metal.*



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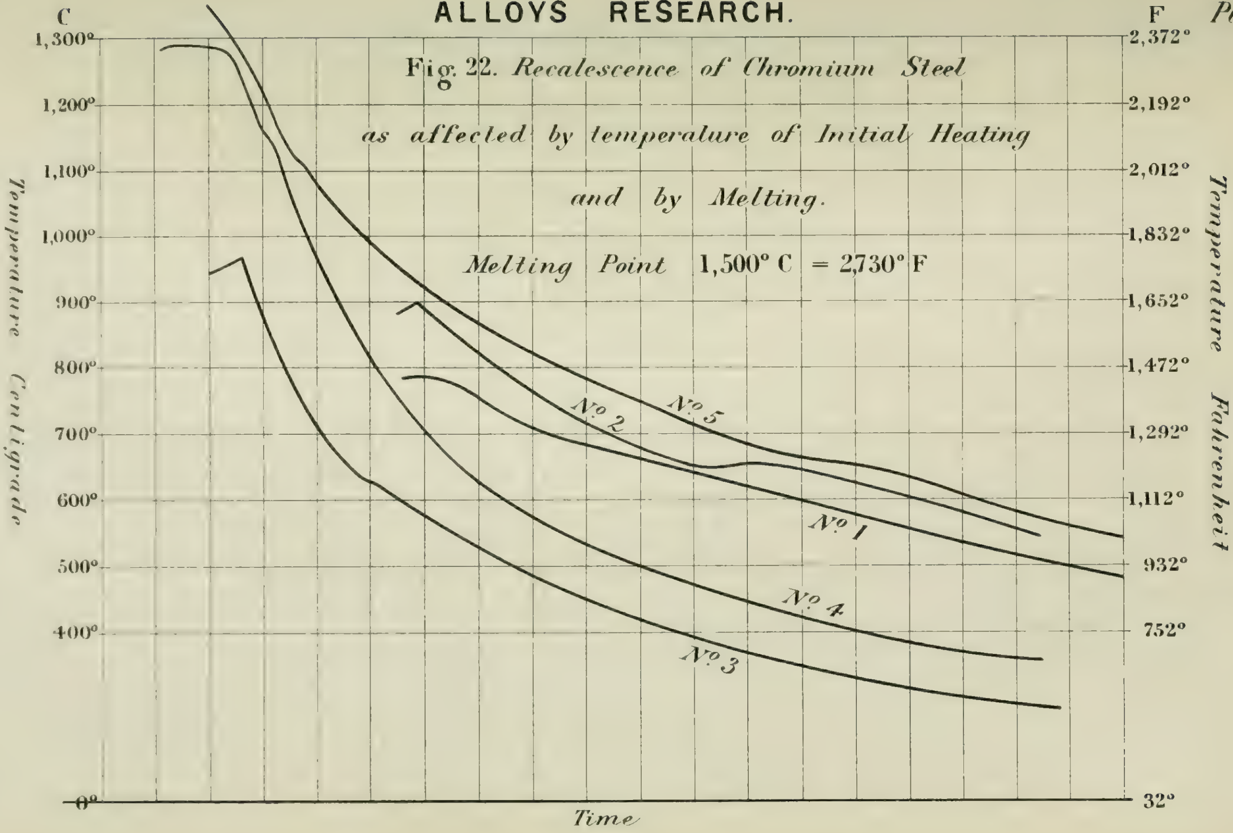

Fig. 22. *Recalescence of Chromium Steel as affected by temperature of Initial Heating and by Melting.*

Melting Point 1,500° C = 2,730° F

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Fig. 23.

Cooling of Gold.

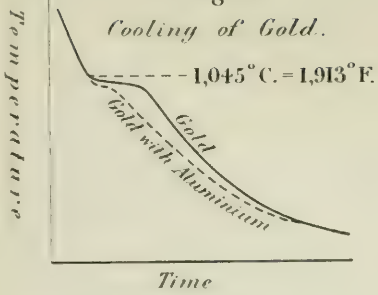


Fig. 24. Cooling of highly Carburized Steel.

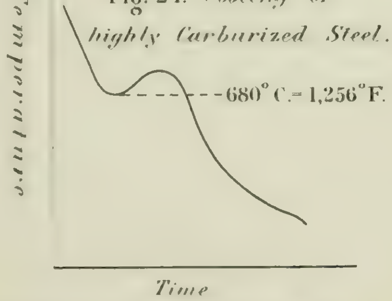
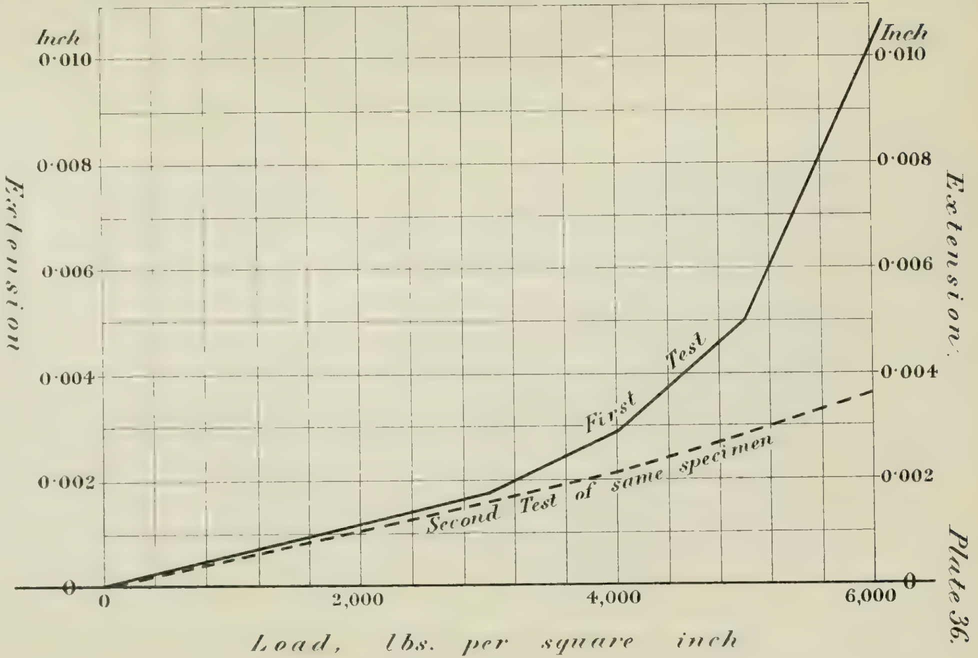


Fig. 25.

Tensile Tests of commercial Pure Copper.



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Heating of Specimens under tensile test.

Fig: 26. *Plan.*

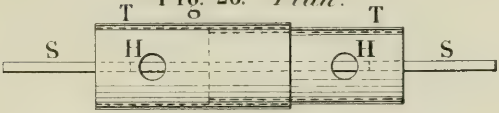


Fig: 27. *Elevation.*

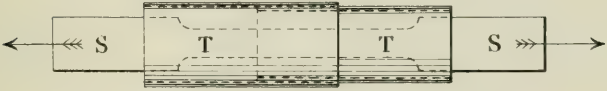
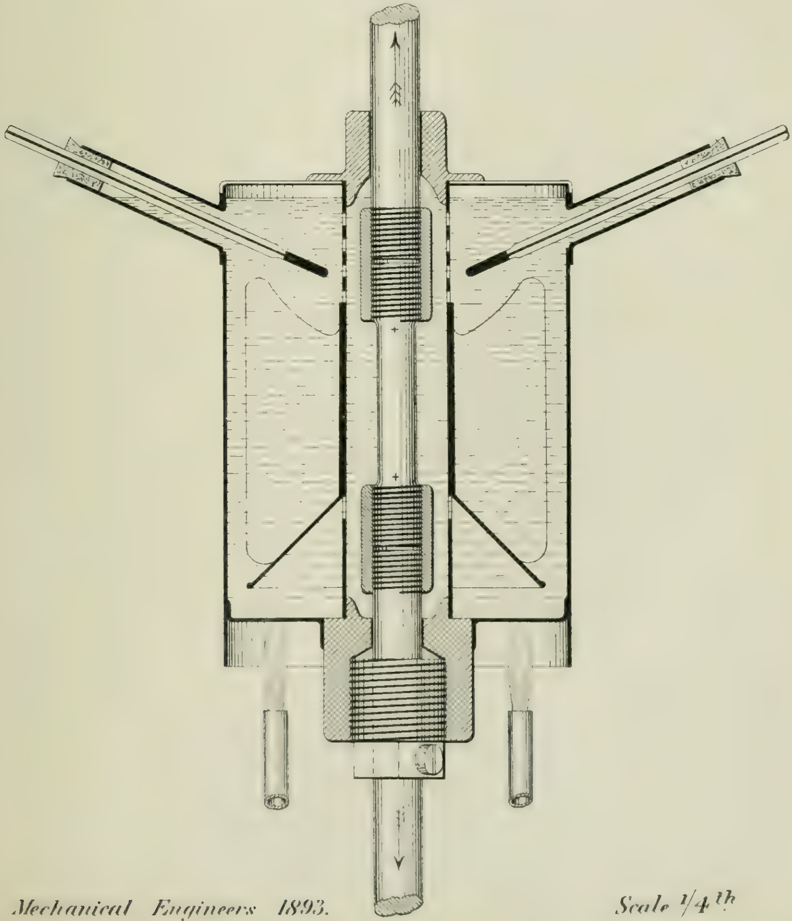


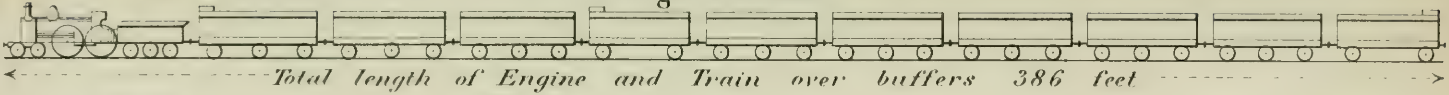
Fig: 28. *Vertical Section.*



Scale 1/4th.

LOCOMOTIVE BOILER DRAUGHT.

Fig. 1. *Train.*



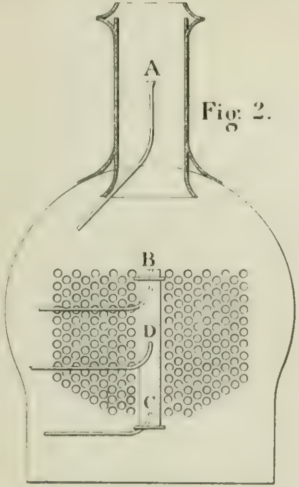


Fig. 2.

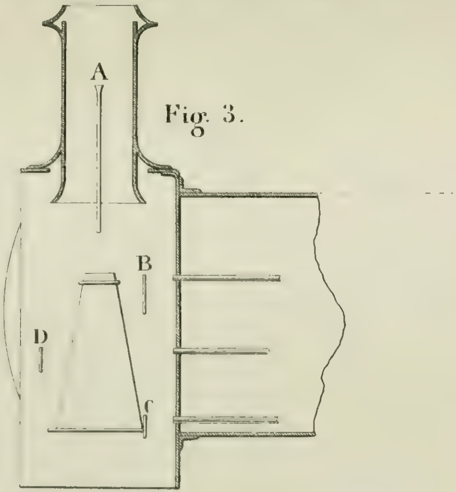
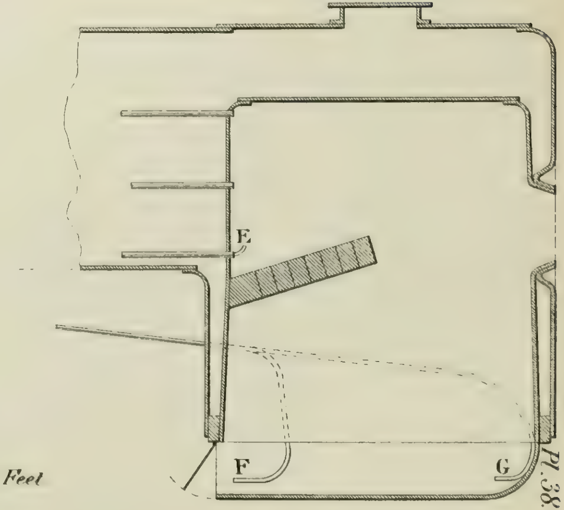


Fig. 3.

Fig. 4.

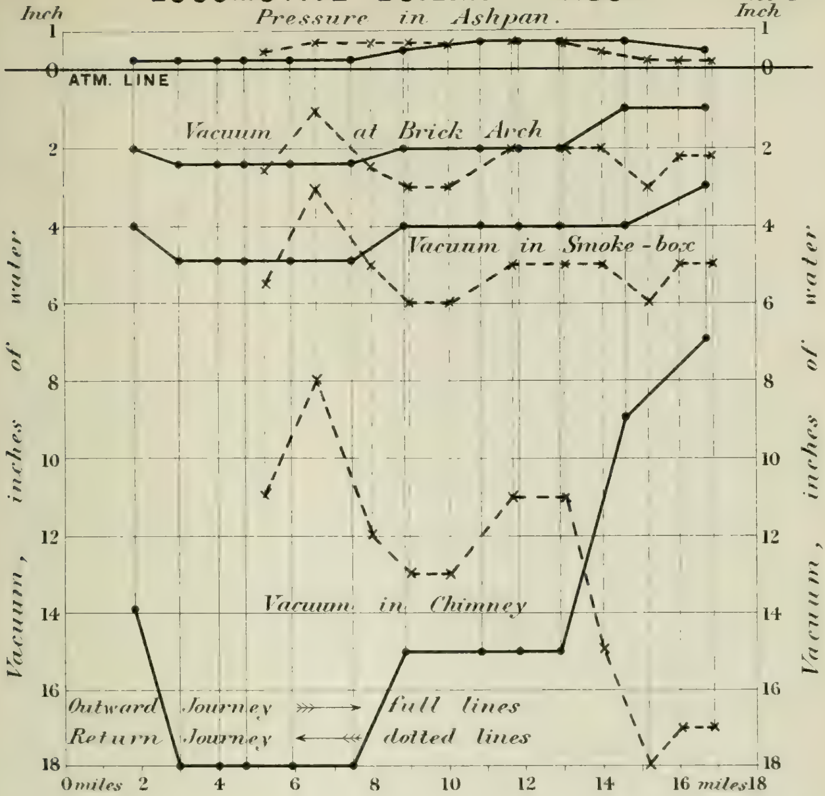


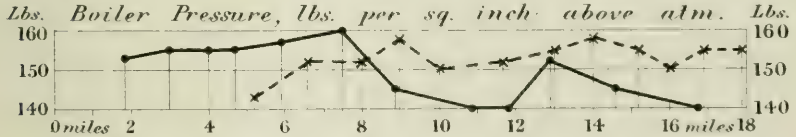
Scale 1/80th

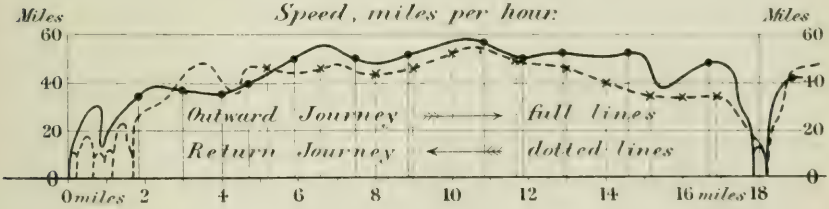
Pl. 38.

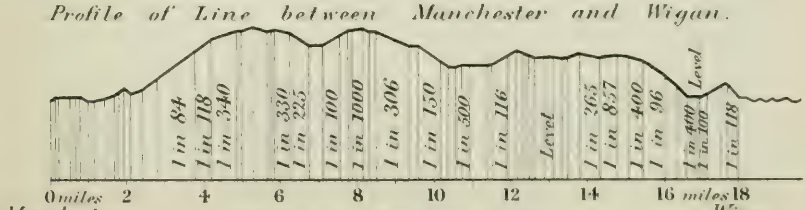
LOCOMOTIVE BOILER DRAUGHT.

Plate 39.



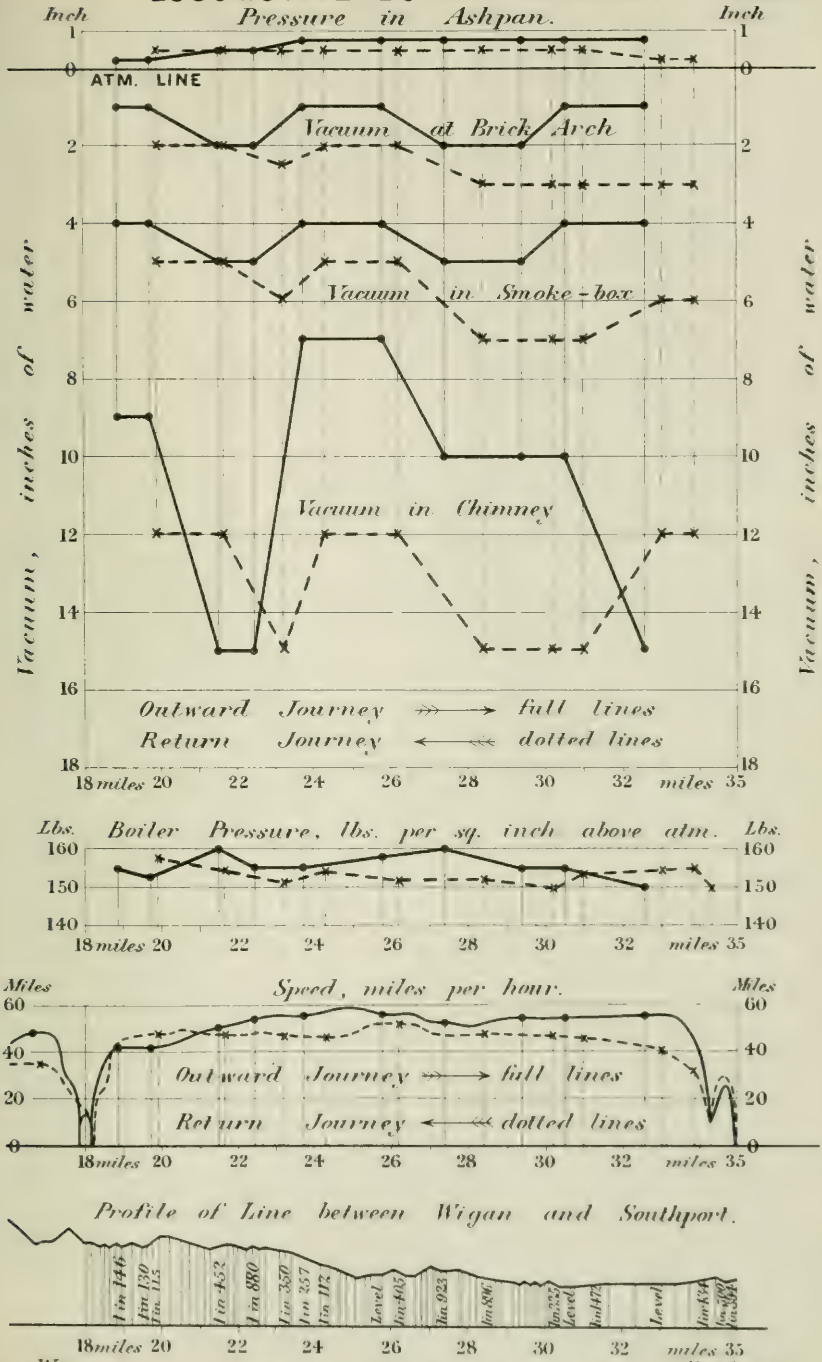






LOCOMOTIVE BOILER DRAUGHT.

Plate 40.



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S

INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847.

PROCEEDINGS.

1893.

PARTS 3–4.

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PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79.

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86.

Sir Edward H. Carbutt, Bart., 1887–88.

Charles Cochrane, 1889.

Joseph Tomlinson, 1890–91.

Institution of Mechanical Engineers.

OFFICERS.

1893.

PRESIDENT.

William Anderson, D.C.L., F.R.S.,	Woolwich.

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The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Thomas Hawksley, F.R.S.,	London.
Jeremiah Head,	London.
John Ramsbottom,	Alderley Edge.
John Robinson,	Leek.
Joseph Tomlinson,	London.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir James N. Douglass, F.R.S.,	London.
Sir Douglas Galton, K.C.B., D.C.L., F.R.S.,	London.
Alexander B. W. Kennedy, F.R.S.,	London.
Edward B. Marten,	Stourbridge.
Sir James Ramsden,	Barrow-in-Furness.
E. Windsor Richards,	Low Moor.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
William Dean,	Swindon.
John Hopkinson, Jun., D.Sc., F.R.S.,	London.
Samuel W. Johnson,	Derby.
Arthur Keen,	Birmingham.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Francis C. Marshall,	Newcastle-on-Tyne.
Henry D. Marshall,	Gainsborough.
Edward P. Martin,	Dowlais.
William H. Maw,	London.
James Platt,	Gloucester.
T. Hurry Riches,	Cardiff.
William H. White, C.B., LL.D., F.R.S.,	London.
J. Hartley Wicksteed,	Leeds.

TREASURER.

Harry Lee Millar.

SECRETARY.

Alfred Bache,

Institution of Mechanical Engineers, 19 *Victoria Street*, *Westminster*, *S.W.*

[Telegraphic address:—*Mech*, *London*. Telephone, 3264.]

Institution of Mechanical Engineers.

ESTABLISHED 1847.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[Telegraph Address and Telephone No. appended within brackets.]

1893.

HONORARY LIFE MEMBERS.

1890. H. R. H. Albert Edward, Prince of Wales, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pall Mall, London, S.W.

1892. Field Marshal H.R.H. the Duke of Cambridge, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Gloucester House, Park Lane, London, W.

1883. Abel, Sir Frederick Augustus, Bart., K.C.B., D.C.L., D.Sc., F.R.S., The Imperial Institute, Imperial Institute Road, London, S.W.; and 40 Cadogan Place, London, S.W. [*Imperial Institute, London.* 8743.]

1878. Crawford and Balcarres, The Right Hon. the Earl of, K.T., F.R.S., 2 Cavendish Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1889. Eiffel, Gustave, 37 Rue Pasquier, Paris.

1888. Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., Trinity College, Dublin.

1883. Kennedy, Professor Alexander Blackie William, F.R.S., 11 Old Queen Street, Westminster, S.W. [*Kinematic, London.*]

1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1888. Rosse, The Right Hon. the Earl of, K.P., D.C.L., LL.D., F.R.S., Birr Castle, Parsonstown, Ireland.

MEMBERS.

1890. Abbott, Arthur Harold, care of Messrs. Octavius Steel and Co., Calcutta, India: (or care of F. C. Abbott, 101 Lambeth Palace Road, London, S.E.)

1878. Abbott, Thomas, Newark Boiler Works, Newark. [*Abbott, Newark.*]

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, Lime Villa, South Woodford, Essex.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1892. Acland, Captain Francis Edward Dyke, Dock House, Billiter Street, London, E.C.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1886. Adamson, Thomas Alfred, 27 Leadenhall Street, London, E.C.

1851. Addison, John, Colehill Cottage, Fulham, London, S.W.

1889. Addy, George, Waverley Works, Effingham Road, Sheffield. [*Milling, Sheffield.*]

1887. Ahmed Bey, Colonel, Imperial Naval Arsenal, Constantinople.

1891. Ahrbecker, Henry Conrad Vandepoel, Morts Dock and Engineering Co., Balmain, Sydney, New South Wales.

1893. Ainley, Henry, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1886. Aisbitt, Matthew Wheldon, 53 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and Savernake Lodge, Chelmsford.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; Norland House, Ramleh, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, Engineer's Department, London County Council; and 8 Sheen Park, Richmond, Surrey.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Co., Albert Works, Penistone Road, Sheffield.

1884. Allen, Alfred Evans, 37 Wellington Street, Hull.

1891. Allen, Marcus, Union Brass and Iron Works, Great Ancoats Street, and Phœnix Iron Works, Jersey Street, Manchester. [*Valves, Manchester. Nat.* 60.]

1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, Exchange Buildings, Mount Stuart Square, Cardiff.

1885. Allen, William Henry, Messrs. W. H. Allen and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, 11 Avenue Victoria, Scarborough.

1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Allott, Charles Sneath, 46 Brown Street, Manchester. [*Allotted, Manchester. Nat.* 1952.]

1876. Allport, Charles James, 24 Woburn Place, Russell Square, London, W.C.; and Whitehall Club, Parliament Street, Westminster, S.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, Cartagena and Herrerias Steam Tramways, 43 Muralla del Mar, Cartagena, Spain: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and Eastdene, St. James' Road, Sutton, Surrey. [*Drilling, London.*]

1867. Amos, James Chapman, Rose Cottage, Fairfax Road, Teddington, S.O., Middlesex.

1891. Anderson, Alexander Southerland, Chief Engineer, Ordnance Department, Ordnance Factory, Cawnpore, India.

1880. Anderson, Edward William, Messrs. Easton, Anderson and Goolden, Erith Iron Works, Erith, S.O., Kent; and Roydon Lodge, Erith, S.O., Kent.

1890. Anderson, Herbert William, Messrs. Hilton Anderson and Co., Manor Works, Halling, near Rochester.

1892. Anderson, John Wemyss, Walker Engineering Laboratories, University College, Liverpool.

1856. Anderson, William, D.C.L., F.R.S., Director-General of Ordnance Factories, Royal Arsenal, Woolwich; and Lesney House, Erith, S. O., Kent.

1891. Anderson, William, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1892. Andrew, Thomas, Rand Club, Johannesburg, Transvaal, South Africa.

1893. Angas, William Moore, Darlington Wagon and Engineering Works, Darlington.

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 22 Walbrook, London, E.C. [*Millwright, London.*]; and East Greenwich Works, London, S.E.

1883. Appleby, Percy Vavasseur, Messrs. Appleby Brothers, 22 Walbrook, London, E.C.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1891. Archbold, John, Eastwood Collieries, Eastwood, R.S.O., Notts.

1881. Archbold, Joseph Gibson, Manager, Blyth Dry Dock, Blyth, Northumberland.

1889. Archer, Charles Frederick, Messrs. Joseph Richmond and Co., 30 Kirby Street, Hatton Garden, London, E.C.

1874. Archer, David, 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.; and 13 Clifton Road, Brockley, London, S.E.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1866. Armstrong, George, Locomotive Department, Great Western Railway, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Messrs. Willans Arnold and Co., Spanish Steel Works, Sheffield; and Friars Close, Barnwell, Northamptonshire.

1887. Arrol, Sir William, Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, Libertad 1357, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 129A Winchester House, Old Broad Street, London, E.C.)

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Tardeo, Bombay, India.

1890. Ashley, Thomas James, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool.

1884. Ashwell, Frank, Victoria Foundry, Sycamore Lane, Leicester. [*Iron, Leicester.* 100.]

1891. Ashworth, Henry, Ollerton, Bolton.

1890. Askham, John Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1890. Askham, Philip Unwin, Messrs. Askham Brothers and Wilson, Yorkshire Steel Works, Napier Street, Sheffield.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1891. Asplen, Bernard, Southall: (or care of W. W. Asplen, Foxton Hall, Royston, Cambridgeshire.)

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1890. Aston, John W., Chief Teacher of Mechanical Science, Municipal School of Art, Birmingham; and Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham.

1886. Atkey, Albert Reuben, Robin Hood Cycle Co., Upper Parliament Street, Nottingham.

1889. Atkinson, Alexander, N. W. Hotel, Lahore, Punjaub, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.)

1875. Atkinson, Edward (*Life Member*), 32 Park Road, West Dulwich, London, S.E.

1890. Atkinson, Edward Turner, London County Council, Spring Gardens, London, S.W.

1892. Atkinson, James, Amherst, Fallowfield, Manchester.

1892. Ault, Edwin, 47 Victoria Street, Westminster, S.W.

1892. Austin, James Meredith, care of Hermann Kühne, 102 Old Broad Street, London, E.C.; and 71 Oakhill Road, East Putney, London, S.W.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1891. Bagshaw, Walter, Victoria Foundry, Batley.

1886. Bailey, William, 14 Delahay Street, Westminster, S.W.

1885. Bailey, William Henry, Albion Works, Salford, Manchester [*Beacon, Salford.*]; and Sale Hall, Cheshire.

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1887. Baillie, Robert Alexander, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 282 Rue Royale, Bruxelles, Belgium.

1890. Bain, George, Locomotive Department, Egyptian Government Railways, Cairo, Egypt.

1880. Bain, William Neish, 40 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1873. Baird, George, St. Petersburg; and Fulmer, Slough.

1890. Baker, Sir Benjamin, K.C.M.G., F.R.S. (*Life Member*), 2 Queen Square Place, Westminster, S.W.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1893. Baldwin, Alfred, M.P., Wilden Iron Works, Stourport.

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Rai Bahadur, Executive Engineer, 4th Division, Chenab Canal, Lahore, Punjaub, India.

1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.

1892. Banister, George Henry, Carriage Department, Royal Arsenal, Woolwich.

1888. Baraclough, William Henry, 36 Temple Street, Birmingham.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham.

1882. Barlow, Henry Bernoulli, 4 Mansfield Chambers, 17 St. Ann's Square, Manchester. [*Monopoly, Manchester.*]

1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1891. Barnes, John Edward Lloyd, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1881. Barnett, John Davis, Assistant Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.

1887. Barningham, James, 41 Victoria Buildings, Victoria Street, Manchester.

1884. Barr, Archibald, D.Sc., Professor of Engineering, The University, Glasgow.

1878. Barr, James, care of William McConnell, Underwood House, Paisley.

1882. Barrett, John James, 5 Chinchpoogly Road, Bombay, India.

1885. Barrie, William, Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., 7B Bluff, Yokohama, Japan.

1887. Barringer, Herbert, 88 Bishopsgate Street Within, London, E.C.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1871. Barry, John Wolfe, 21 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]

1883. Bartlett, James Herbert, Middlesbrough, Kentucky, United States.

1887. Bate, Capt. Charles McGuire, R.E., War Office, Whitehall, London, S.W.

1885. Bateman, Henry, Superintending Engineer, Rangoon Tramways, Rangoon, India.

1891. Bates, Henry, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester; and 30 Halliwell Terrace, Trafford Road, Salford, Manchester.

1891. Battle, Arthur Edwin, 359–361 Collins Street, Melbourne, Victoria: (or care of F. G. Battle, Whitehall, Potterhanworth, Lincoln.) [Reuter's Agency: *Battle, Melbourne.*]

1892. Baxter, Peter Macleod, Departamento de Talleres, Minas de Rio Tinto, Huelva, Spain.

1889. Bayford, William James, Engineer and Manager, Messrs. Meakin and Co., Brewers, Delhi, India.

1872. Bayliss, Thomas Richard, Belmont, Northfield, Birmingham.

1891. Baynes, John, Midland Railway-Carriage and Wagon Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1877. Beale, William Phipson, Q.C., 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1893. Beare, Thomas Hudson, F.R.S.E., Professor of Engineering, University College, Gower Street, London, W.C.

1893. Beastow, William Henry, Messrs. Brooks and Doxey, Union Iron Works, West Gorton, Manchester; and Junction Iron Works, Miles Platting, Manchester; and 157 Hyde Road, West Gorton, Manchester.

1891. Beatty, Hazlitt Michael, Locomotive Superintendent, Western Railway, Cape Government Railways, Salt River, near Cape Town, Cape Colony; and Rosclare Camp Ground, Rondebosch, near Cape Town, Cape Colony.

1880. Beaumont, William Worby, 33 Norfolk Street, Strand, London, W.C.; and Melford, Palace Road, Tulse Hill, London, S.W.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, Enfield House, Fairlop Road. Leytonstone, London, N.E.

1891. Beckwith, George Charles, 17 Wind Street, Swansea. [*Beckwith, Swansea.*]

1875. Beckwith, John Henry, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Parkhurst, Middlesbrough.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1884. Beetlestone, George John, Sudbrook Works, near Chepstow.

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough; and Linthorpe, Middlesbrough. [*Bells, Middlesbrough.* 5510.]

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]

1879. Bellamy, Charles James, 195 Earl's Court Road, South Kensington, London, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1890. Berkley, James Eustace, Locomotive and Carriage Superintendent, H.H. the Nizam's Guaranteed State Railways, Secunderabad, India.

1878. Berrier-Fontaine, Marc, Directeur des Constructions navales, Toulon, France.

1893. Berry, Henry, Croydon Works, Leeds.

1893. Berry, John Ferrier, care of Messrs. Howard Farrar and Co., P. O. Box 455, Johannesburg, Transvaal, South Africa.

1890. Bertram, Alexander, Wigan Coal and Iron Works, Wigan.

1891. Bertram, David Noble, Messrs. Bertrams, St. Katherine's Works, Sciennes, Edinburgh.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1891. Best, Francis Edward, 1 Swan Walk, Chelsea Embankment, London, S.W.

1893. Betts, Samuel, Locomotive Superintendent, Oxelösund-Fleu-Westmanlands Railway, Eskilstuna, Sweden.

1891. Bevis, Alfred William, The Nest, Harborne, Birmingham.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1892. Bickle, Thomas Edwin, Messrs. Bickle and Co., Great Western Docks, Plymouth. [*Engineers, Plymouth.* 176.]

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, care of Bank of Bengal, Calcutta, India: (or 8 Canynge Square, Clifton, Bristol.)

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1888. Billinton, Robert John, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1890. Bingham, Charles Henry, Messrs. Walker and Hall, Electro Works, Howard Street, Sheffield. [*Bingham, Sheffield.*]

1887. Binnie, Alexander Richardson, Engineer, London County Council, Spring Gardens, London, S.W.; and 14 Campden Hill Gardens, Notting Hill, London, W.

1877. Birch, Robert William Peregrine, 5 Queen Anne's Gate, Westminster, S.W.

1891. Bird, George, Messrs. James Bartle and Co., Western Iron Works, Notting Hill, London, W.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead. [*Blackthorn, Newcastletyne.*]

1891. Black, William, 72 Bute Road, Cardiff.

1891. Blackburn, Arthur Henry, Fuel Economizer Co., Matteawan, New York, United States.

1891. Blackburn, George William, Messrs. T. Green and Son, Smithfield Iron Works, Leeds.

1890. Blackburn, John, Resident Engineer, Colne Valley Water Works, Bushey, Watford.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, Naval Construction and Armaments Works, Barrow-in-Furness.

1892. Blechynden, John, Shanghai Engine Works, Birt's Wharf, Shanghai, China. [*Steam, Shanghai.* 176.]

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, Catherine Chambers, 8 Catherine Street, Strand, London, W.C.

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1892. Booth, John William, Union Foundry, Rodley, near Leeds.

1890. Booth, Robert, 110 Cannon Street, London, E.C.

1883. Booth, William Stanway, Messrs. John Jameson and Son, Bow Street Distillery, Dublin.

1892. Borns, George Maximilian, Upper Plain, Masterton, North Island, New Zealand: (or care of Messrs. Maw Dredge and Hollingsworth, 35 and 36 Bedford Street, Strand, London, W.C.)

1880. Borodin, Alexander, Engineer-Director, Russian South Western Railways, Kieff, Russia.

1888. Borrows, William, Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helen's, Lancashire.

1891. Boswell, Samuel, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1885. Boughton, Henry Francis, Parade Chambers, Sheffield; and The Poplars, Stairfoot, Barnsley. [*Boughton, Barnsley. Nat.* 625, *Sheffield.*]

1888. Boulding, Sidney, Messrs. Green and Boulding, 21 Featherstone Street, London, E.C.

1886. Boult, Alfred Julius, Messrs. W. P. Thompson and Boult, 323 High Holborn, London, W.C.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1886. Bourne, Thomas Johnstone, Imperial Chinese Railways, Tientsin, China: (or care of Mrs. Bourne, 16 Park Road, Southborough, Tunbridge Wells.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1891. Bousfield, John Ebenezer, 4 South Street, Finsbury, London, E.C. [*Invention, London.* 169.]

1879. Bovey, Henry Taylor, LL.D., Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. Bowen, Edward (*Life Member*), Locomotive and Carriage Superintendent, Porto Alegre and New Hamburg Railway, Rio Grande do Sol, Brazil: (or care of Benjamin Packham, 122 Upper Lewes Road, Brighton.)

1858. Bower, John Wilkes (*Life Member*), Meredale, Rugby Road, Leamington Spa.

1892. Bowker, Arthur F., Engineer and Manager, Mid-Kent Water Works, High Street, Snodland, S.O., Kent.

1893. Boyd, James Tennant, Boyd's Ice Factory, Bombay, India.

1890. Boyd, John White, 6 Oswald Street, Glasgow.

1884. Boyer, Robert Skeffington, 46 Mount Stuart Square, Cardiff.

1882. Bradley, Frederic, Sandhills, Liverpool; Clensmore Foundry, Kidderminster; and Wolverley House, Southport.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich. [*Braithwaite, Westbromwich.*]

1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., LL.D., F.R.S., Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1892. Brand, David Jollie, Messrs. Brand and Dryburgh, Cleveland Foundry and Engine Works, Townsville, North Queensland.

1888. Bratt, Augustus Hicks Henery, Le Kueh Coal and Iron Mines, Kiangsu, North China; Astor House, Shanghai, China: (or care of Messrs. David Owen and Co., 50 Exchange Chambers, Bixteth Street, Liverpool.) [*Bratt, Shanghai.*]

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's.

1889. Brebner, Samuel Gordon, Chief Mechanical Engineer, Small Arms Ammunition Factory, Kirkee, Poona, India.

1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham. [*Breeden, Birmingham.*]

1891. Brewster, Edwin Henry George, 12 Delahay Street, Westminster, S.W.

1890. Brewster, Walter Seckford, Messrs. Beyer Peacock and Co.; High Street, Carlton, Hurstville, near Sydney, New South Wales.

1891. Bridie, Ronald Hope, St. Benet's Place, Gracechurch Street, London, E.C. [*Enwheeling, London.*]

1887. Brier, Henry, Scotch and Irish Oxygen Co., Rosehill Works, Polmadie, Glasgow.

1889. Briggs, Charles, Jun., care of Robert Briggs, Howden.

1881. Briggs, John Henry, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and Howden.

1886. Bright, William, Manager, Fairwood Tin-Plate Works, Gowerton, R.S.O., Glamorganshire.

1891. Broadbent, William, Messrs. Thomas Broadbent and Sons, Central Iron Works, Huddersfield. [*Broadbent, Huddersfield.* 102.]

1891. Brock, Cameron William Harrison, 68 Victoria Street, Westminster, S.W.

1865. Brock, Walter, Messrs. Denny and Brothers, Engine Works, Dumbarton.

1890. Brodie, John Alexander, 3 Cook Street, Liverpool.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1890. Brogden, Thomas, Messrs. Appleby and Brogden, Sandside, Scarborough.

1892. Bromiley, William J., Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1892. Brooke, John Walter, Adrian Iron Works, Lowestoft.

1892. Brooke, Robert Grundy, Messrs. Holden and Brooke, St. Simon's Works, Salford, Manchester. [*Influx, Manchester.*]

1884. Brook-Fox, Frederick George, care of Messrs. Grindlay, Groom and Co., Bombay, India: (or care of Messrs. H. S. King and Co., 65 Cornhill, London, E.C.)

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1891. Brotherhood, Arthur Maudslay, 15 and 17 Belvedere Road, Lambeth, London, S.E.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 15 Hyde Park Gardens, London, W. [*Brotherhood, London.*]

1886. Brown, Andrew, Messrs. T. Cosser and Co., McLeod Road Iron Works, Kurrachee, India: (or care of P.B. Brown, 187 Sutherland Road, Sheffield.)

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1891. Brown, Arthur Mogg, P.O. Box 1260, Johannesburg, Transvaal, South Africa.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Intercolonial Railway of Canada, Moncton, New Brunswick, Canada.

1889. Brown, Frederick Alexander William, Lieutenant R.A., Inspector of Ordnance Machinery, Mauritius: (or 42 Fermoy Road, St. Peter's Park, London, W.)

1881. Brown, George William, Messrs. Huntley Boorne and Stevens, Reading Tin Works, Reading.

1887. Brown, James, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne.

1892. Brown, James Fiddes, 147 Woodbridge Road, Ipswich.

1884. Brown, Oswald, 28 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1890. Brown, Robert, Manor House Engine Works, Far Cotton, Northampton.

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1892. Brown, William, Messrs. Siemens Brothers and Co., Woolwich.

1887. Browne, Frederick John, Messrs. Austin Wood Browne and Co., Austin Foundry, Parkfield Street, Islington, London, N.

1874. Browne, Tomyns Reginald, Deputy Locomotive Superintendent, East Indian Railway, Jamalpur, Bengal, India: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1874. Bruce, Sir George Barclay, 3 Victoria Street, Westminster, S.W.

1889. Bruce, Robert, 30 Great St. Helen's, London, E.C. [*Tangential, London.*]

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 23 Roland Gardens, South Kensington, London, S.W.

1888. Bruff, Charles Clarke, Coalport China Co., Coalport, near Ironbridge, Salop.

1873. Brunel, Henry Marc, 21 Delahay Street, Westminster, S.W. [3024.]

1892. Brunlees, John, 12 Victoria Street, Westminster, S.W. [3245.]

1891. Brunner, Adolphus, 55 Am Königin Strasse, Munich, Bavaria: (or care of L. F. Brunner, 257 Romford Road, Forest Gate, London, E.)

1887. Brunton, Philip George, Resident Engineer, Department of Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Lea Bridge, Clapton, London, N.E.

1892. Buckley, John T., Messrs. Stevenson and Co., Canal Foundry, Preston; and 50 Poulton Street, Kirkham, near Preston.

1873. Buckley, Robert Burton, Arrah, Shahabad, Bengal, India: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1878. Buddicom, Harry William, Penbedw, Nannerch, near Mold.

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile (or care of Messrs. Rose-Innes Cox and Co., 4 Fenchurch Avenue, London, E.C.)

1881. Bulkley, Henry Wheeler, N.Y. Times Building, 41 Park Row, New York, United States.

1884. Bullock, Joseph Howell, General Manager, Pelsall Coal and Iron Works, near Walsall; and Glenhurst, Lichfield Road, Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1891. Bumsted, Francis Dixon, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1884. Bunning, Charles Ziethen, The Borax Co., 9 Mehmet Ali Pacha Khan, Constantinople.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Locomotive Superintendent, Costa Rica Railways, San José, Costa Rica: (or Gaisford House, Gaisford Street, Kentish Town, London, N.W.)

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1891. Burgess, Francis Chassereau Boughey, Office of Director General of Railways, Technical Section, Simla, India.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1893. Burnes, Thomas, Fleet Engineer, R.N.; H.M.S. "Penelope," Simon's Town, Cape Colony.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

1878. Burnett, Robert Harvey, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1887. Burstal, Edward Kynaston, Messrs. Stevenson and Burstal, 38 Parliament Street, Westminster, S.W.

1890. Burstall, Henry Robert John, 14 Old Queen Street, Westminster, S.W.; and 76 King's Road, London, N.W.

1884. Butcher, Joseph John, Heine Safety Boiler Co., Electrical Exchange Building, 136 Liberty Street, New York, United States.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1892. Butler, Henry William, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1891. Butler, James, Victoria Iron Works, Halifax; and Longfield, Halifax.

1888. Butter, Frederick Henry, Carriage Department, Royal Arsenal, Woolwich; and 4 Hanover Road, Brookhill Park, Plumstead.

1891. Butter, Henry Joseph, Messrs. Tannett Walker and Co., Leeds; and Claremont, Burrage Road, Plumstead.

1892. Byrne, Francis Furlong, Engineer, Harbour Office, Drogheda, Ireland. [*Byrne, Engineer, Drogheda.*]

1887. Caiger, Emery John, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1886. Cairnes, Frederick Evelyn, Bridgewater Hotel, Worsley, near Manchester.

1889. Callan, William, River Plate Fresh Meat Co., 2 Coleman Street, London, E.C.

1886. Cambridge, Henry, Stuart Chambers, Mount Stuart Square, Cardiff.

1893. Campbell, Andrew Chisholm, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1877. Campbell, Angus, Logie, Mussoorie, N. W. Provinces, India.

1880. Campbell, Daniel, Messrs. Campbell and Schultz, Botolph House 10 Eastcheap, London, E.C. [*Duke, London.* 1893.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1893. Campbell, James Alexander Miller, Messrs. James Campbell and Sons, Vulcan Engine Works, William Moult Street, Liverpool.

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1892. Campbell, William Walker, Messrs. Campbell and Calderwood, Soho Engine Works, Paisley.

1885. Capito, Charles Alfred Adolph, 2 Penywern Road, Earl's Court, London, S.W.

1892. Capper, David Sing, Professor of Mechanical Engineering, King's College, Strand, London, W.C.

1860. Carbutt, Sir Edward Hamer, Bart., 19 Hyde Park Gardens, London, W.; and Nanhurst, Cranleigh, Guildford.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Burma State Railways, Insein, Burma; care of Messrs. King King and Co., Bombay, India: (or care of Rev. J. H. Cardew, Wingfield Rectory, Trowbridge.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Marlow House, New Swindon, Wiltshire.

1887. Carlyle, Thomas, Lieutenant R.A., Inspector of Ordnance Machinery, Singapore: (or 72 Glyndon Road, Plumstead.)

1892. Carnegie, David, Royal Laboratory, Royal Arsenal, Woolwich.

1869. Carpmael, Frederick, 106 Croxted Road, West Dulwich, London, S.E.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, 1 West Pier, London Docks, London, E.

1892. Carrack, Charles, Messrs. Crossley Brothers, 5 Hounds Gate, Nottingham.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Newbrough Lodge, Fourstones, R.S.O., Northumberland. [*Wardale, Gateshead.*]

1888. Carrick, Samuel Stewart, Superintendent Engineer, Shaw Savill and Albion Steamship Co., 34 Leadenhall Street, London, E.C.

1885. Carter, Herbert Fuller, Calle de Gante 8, Ciudad de Mexico, Mexico: (or care of H. Maynard Carter, 126 Wool Exchange, Basinghall Street, London, E.C.)

1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1891. Carter, William Charles, Mansion House Chambers, Queen Victoria Street, London, E.C. [*Tympanum, London.*]

1890. Carver, Henry Clifton, Messrs. Coates and Carver, 3 Cross Street, Manchester.

1888. Castle, Frank, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Caswell, Samuel John, 31 Sakai Machi, Kobe, Japan.

1892. Causer, William George, Brighton Villa, Handsworth, R.O., Birmingham.

1883. Cawley, George, 29 Great George Street, Westminster, S.W.

1892. Chadwick, Osbert, C. M. G., Crown Agents' Department, Colonial Office, Downing Street, London, S.W.; and 11 Airlie Gardens, Kensington, London, W.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1892. Chalmers, George, St. John del Rey Mining Co., 28 Tower Chambers, Finsbury Pavement, London, E.C.

1886. Chalmers, John Reid, 18 Hemingford Road, Barnsbury, London, N.

1884. Chamberlain, John, Hydro-Oxy Gas Company, 11 Salisbury Square, Fleet Street, London, E.C.

1890. Chandler, Noel, Cannock Chase Foundry and Engine Works, Hednesford, near Stafford.

1887. Chapman, Alfred Crawhall, 2 St. Nicholas' Buildings, Newcastle-on-Tyne.

1888. Chapman, Arthur, Messrs. Marillier and Edwards, 1 Hastings Street, Calcutta, India; Great Eastern Hotel, Calcutta, India: (or St. Andrew's Cottage, Bury St. Edmund's.)

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W. [*Tubalcain, London.*]; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.

1893. Charlesworth, Sheard, Messrs. S. Charlesworth and Co., Richmond Hill Iron Works, Oldham. [*Charlesworth, Engineers, Oldham.* 63.]

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1890. Chater, John Richard, Madras Railway, Madras, India; and care of John Chater, 223 Peckham Rye, London, S.E.

1891. Chatterton, Alfred, Professor of Engineering, College of Engineering, Madras, India.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and High Lawn, Broad Oak Park, Worsley, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, The Terrace, H.M. Dockyard, Sheerness.

1877. Chisholm, John, General Manager, Messrs. A. and J. Stewart and Clydesdale, 41 Oswald Street, Glasgow; and 9 Corunna Street, Dumbarton Road, Glasgow.

1880. Churchward, George Dundas, Locomotive Superintendent, Imperial Chinese Railways, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough.)

1891. Clark, Augustus, Bowman's Heirs, Pernambuco, Brazil.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1889. Clark, Thomas Alexander, Superintendent of Workshops, George Heriot's Hospital School, Edinburgh.

1885. Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1891. Clarkson, Thomas, Fairholme, Egmont Road, Sutton, Surrey.

1892. Clay, Charles Butler, National Telephone Co., Oxford Court, Cannon Street, London, E.C.

1886. Clayton, Samuel, St. Thomas' Engine Works, Sunbridge Road, Bradford.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1890. Cleathero, Edward Thomas, Messrs. Cleathero and Nichols, Phœnix Works, Boleyn Road, Kingsland, London, N.; and 16 Tollington Place, London, N.

1890. Cleaver, Arthur, Engineer, Nottingham Laundry Co., Sherwood, near Nottingham; and Hornby House, Sherwood, near Nottingham.

1890. Cleland, William, Sheffield Testing Works, Blonk Street, Sheffield.

1871. Cleminson, James, Dashwood House, 9 New Broad Street, London, E.C. [*Catamarca, London.*]

1873. Clench, Frederick, Newland House, Lincoln.

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, Engineers' Department, London County Council, Spring Gardens, London, S.W.

1882. Coates, Joseph, 117 Cannon Street, London, E.C.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1889. Coey, Robert, Assistant Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1889. Colam, William Newby, Billiter Buildings, Billiter Street, London, E.C. [*Colam, London.*]

1892. Cole, Henry Aylwin Bevan, 79½ Gracechurch Street, London, E.C. [*Carbuncle, London.*]

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.

1892. Collen, Robert Henry, 10 Dover Road, Northfleet, S.O., Kent.

1884. Collenette, Ralph, Bowling Iron Works, Bradford.

1884. Colquhoun, James, Abbotsford, The Shrubbery, Weston-super-Mare.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.

1889. Common, John Freeland Fergus, 4 Bute Crescent, Cardiff.

1881. Compton-Bracebridge, John Edward, Messrs. Easton Anderson and Goolden, 3 Whitehall Place, London, S.W.

1888. Constantine, Ezekiel Grayson, 32 Victoria Street, Manchester. [*Constant, Manchester.*]

1886. Conyers, Sidney Ward, Railway Construction Branch, Public Works Department, Sydney, New South Wales.

1874. Conyers, William, National Mortgage and Agency Co. of New Zealand, Melbourne, Victoria.

1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helen's, Lancashire.

1892. Cooke, Rupert Thomas, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E. [*Patella, London.* 1140.]

1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.

1891. Cooper, Myles, 36 Victoria Street, Manchester.

1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1881. Copeland, Charles John, 11 Redcross Street, Liverpool.

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1892. Corin, Philip Burne, Messrs. J. M. B. Corin and Son, Anchor Foundry, Penzance.

1878. Cornes, Cornelius, 6 Norfolk Crescent, Bath [*Stothert, Cornes, Bath.*]; and 76 Cannon Street, London, E.C. [*Stothert, Cornes, London.*]

1848. Corry, Edward, 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1883. Cotton, Henry Streatfeild, London Hydraulic Power Co., Palace Chambers, Bridge Street, Westminster, S.W.

1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.

1868. Coulson, William, Carlton Grove, Carlton Miniott, Thirsk.

1878. Courtney, Frank Stuart, Messrs. Easton Anderson and Goolden, 3 Whitehall Place, London, S.W.; and 76 Redcliffe Square, South Kensington, London, S.W.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1880. Cowper, Charles Edward, Messrs. E. A. Cowper and Son, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, Messrs. E. A. Cowper and Son, 6 Great George Street, Westminster, S.W.

1892. Cowper-Coles, Sherard Osborn, 11 Hatton Garden, London, E.C.; and 16 Adam Street, Manchester Square, London, W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1887. Crabbe, Alexander, 4 Hawkhill Place, Dundee.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1889. Cribb, Frederick James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1884. Crighton, John, Messrs. Crighton and Co., 20 Exchange Buildings, St. Mary's Gate, Manchester. [*Vacuum, Manchester.*]

1893. Crippin, Thomas Henry, Messrs. John Hetherington and Sons, Manchester; and 66 Chorlton Road, Manchester.

1883. Croft, Henry, M.P., Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 14 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1891. Crosland, Joseph, Messrs. Seebohm and Dieckstahl, Dannemora Steel Works, Sheffield; and Stanley Avenue, Birkdale, Southport.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Eirianfa, Llangollen.

1890. Cross, Robert James, Consulting Engineer, Great Western Steamship Co.; care of Messrs. Mark Whitwill and Son, Bristol.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1889. Cullen, William Hart, Resident Engineer, The Aluminium Co., Oldbury, near Birmingham.

1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.; and 4 Westcombe Park, Blackheath, London, S.E.

1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]; and 16 Great George Street, Westminster, S.W.

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India; and Cumbala Hill, Bombay, India.

1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]

1891. Daglish, Harry Bolton, Messrs. Robert Daglish and Co., St. Helen's Engine and Boiler Works, St. Helen's, Lancashire.

1883. D'Albert, Charles, Société des Anciens Établissements Hotchkiss et Cie., 6 Route de Gonesse, St. Denis, Seine, France.

1890. Dalby, William Ernest, Engineering Department, The University, Cambridge.

1889. Dalgarno, James Robert, Danesford, Countess Wells Road, Mannofield, Aberdeen.

1893. Dall, John, Messrs. Harland and Wolff, Belfast.

1893. Dalrymple, Alexander, Superintendent Engineer, Hall Line of Steamers, 19 Tower Buildings N., Water Street, Liverpool.

1881. D'Alton, Patrick Walter, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Fern Bank, Horsforth, Leeds.

1891. Daniels, Thomas, Messrs. Nasmyth Wilson and Co., Patricroft, Manchester.

1888. Darbishire, James Edward, 110 Cannon Street, London, E.C.

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W.

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1880. Davies, Charles Merson, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow; and Laurieville, Queen's Drive, Crosshill, Glasgow.

1885. Davies, Edward John Mines, 16 Camden Street, Oakley Square, London, N.W.

1891. Davies, John Hubert, P.O. Box 455, Johannesburg, Transvaal, South Africa.

1868. Davis, Henry Wheeler, 53 New Broad Street, London, E.C.

1876. Davis, Joseph, Engineer's Office, Lancashire and Yorkshire Railway, Manchester.

1877. Davison, John Walter, care of Mrs. Channon, 23 Streatley Road, Brondesbury, London, N.W.

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield. [*Motor, Sheffield.*]

1892. Davy, William James, 161 Huddleston Road, Tufnell Park, London, N.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, 50 Chelsea Road, Southsea, Portsmouth.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1875. Dawson, Edward, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1890. Day, George Cameron. Messrs. Day Summers and Co., Northam Iron Works, Southampton.

1886. Dayson, William Ogden, Blaenavon Works, Blaenavon, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, 32 Victoria Street, Westminster, S.W.

1880. Deacon, Richard William, Messrs. Samuel Fisher and Co., Nile Foundry, Birmingham; and 16 Carpenter Road, Edgbaston, Birmingham.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1887. Deas, James, Clyde Navigation, Glasgow.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine-et-Oise, France. [*Decăuville, Corbeil.*]

1890. Deeley, Richard Mountford, Locomotive Department, Midland Railway, Derby; and 10 Charnwood Street, Derby.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1889. Defries, Wolf, Messrs. Defries and Sons, 147 Houndsditch, London, E. [*Defries, London.*]

1882. Denison, Samuel, Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1892. Dennis, George D., Superintendent Engineer to William Whiteley, 147 Queen's Road, London, W.

1888. Dent, Charles Hastings, London and North Western Railway. Lime Street Station, Liverpool.

1883. Dick, Frank Wesley, Palmers Shipbuilding and Iron Works, Jarrow.

1891. Dick, John Norman, Government Marine Surveyor, Penang, Straits Settlements.

1890. Dickinson, Alfred, Engineer, South Staffordshire Tramways, Darlaston, Wednesbury.

1891. Dickinson, Douglas Holt, The Wood, Maybury, near Woking.

1891. Dickinson, James Clark, Palmer's Hill Engine Works, Sunderland.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1892. Dickinson, Richard Elihu, Bowling Iron Works, Bradford.

1892. Dickinson, Richard Henry, Locomotive Superintendent, Birmingham Central Tramways, Kyotts Lake Depôt, Birmingham.

1875. Dickinson, William, Messrs. Easton Anderson and Goolden, 3 Whitehall Place, London, S.W.

1888. Dickson, George Manners, Assistant Engineer, Calcutta Water Works, Municipal Office, Calcutta, India.

1886. Dixon, Robert, 10 Claremont Street, Newcastle-on-Tyne.

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.*]

1887. Dixon, William Basil, Earle's Shipbuilding and Engineering Works, Hull.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, Superintendent Engineer, Messrs. Harris and Co.'s Iron Works, Samarang, Java: (or care of Miss Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1889. Dolby, Ernest Richard, 8 Prince's Street, Westminster, S.W.

1880. Donald, James, Superintendent Engineer, Messrs. James Fisher and Sons, Fisher's Buildings, Barrow-in-Furness.

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1891. Donovan, Edward Wynne, Messrs. J. S. Leach and Co., Mount Street Works, Harpurhey, Manchester.

1865. Douglas, Charles Prattman, Consett Iron Works, Consett, R.S.O., County Durham; and Parliament Street, Consett, R.S.O., County Durham.

1879. Douglass, Sir James Nicholas, F.R.S., Stella House, Dulwich, London, S.E.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1891. Douglass, William James, Messrs. Douglass Brothers, Globe Iron Works, Blaydon-on-Tyne, R.S.O., County Durham.

1887. Douglass, William Tregarthen, 17 Victoria Street, Westminster, S.W.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hatfield House, Hatfield, near Doncaster.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Belle Vue, Marton Road, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W. [*Gaseous, London.*]

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1890. Drewet, Tom, Government Senior Inspector of Steam Boilers, Town Custom House, Bombay, India.

1886. Drummond, Dugald, Messrs. D. Drummond and Son, Glasgow Railway Engineering Works, Helen Street, Govan, Glasgow. [*Expansion, Glasgow.* 1699.]

1889. Drummond, Richard Oliver Gardner, De Beer's Diamond Mining Co., Kimberley, South Africa.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 28 Victoria Street, Westminster, S.W. [*Doucine, London.*]; and Kilmux, Leven.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1892. Dunlop, James, Victoria Jubilee Technical Institute, Byculla, Bombay, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Charlcombe Grove, Lansdown, Bath.

1890. Dunn, Hugh Shaw, Engineer, Caprington Collieries, Kilmarnock.

1885. Durham, Frederick William, 27 Leadenhall Street, London, E.C. [*Oilring, London.*]; and Glemham Lodge, New Barnet.

1886. Duvall, Charles Anthony, Messrs. E. Bennis and Co., Lancashire Stoker Works, Deansgate Foundry, Bolton.

1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1892. Eastwood, Thomas Carline, Messrs. Eastwood Swingler and Co., Victoria and Railway Iron Works, Derby. [*Swingler, Derby.*]

1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1893. Eden, The Hon. Francis Fleetwood, Los Talleres de Sola, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or Edenthorpe, Doncaster.)

1887. Edlin, Herbert William, P.O. Box 199, Cape Town, Cape Colony: (or The Limes, Ellerton Road, Surbiton, R. O., Kingston-on-Thames.)

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1871. Edwards, Edgar James, 42 Rye Hill Park, Peckham, London, S.E.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1888. Ellery, Henry George, 7 Fernbank Road, Redland, Bristol.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., Houghton-le-Spring, near Fence Houses. [*Elliot Company, London.*]

1892. Elliott, Archibald Campbell, D.Sc., Professor of Engineering, University College of South Wales and Monmouthshire, Cardiff.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]

1869. Elliott, Henry Worton, Selly Oak Works, near Birmingham. [*Elmeco, Birmingham.*]

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1892. Ellis, Joseph S., Messrs. Edward Finch and Co., Bridge Works, Chepstow; and Myrtle Cottage, Chepstow.

1880. Ellis, Oswald William, 6 Grosvenor Place, Jesmond, Newcastle-on-Tyne. [*Robey, Newcastle-on-Tyne.*]

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India; and Altamont Road, Cumbala Hill, Bombay, India.

1875. Elwell, Thomas, 223 Avenue de Paris, Plaine St. Denis, Seine, France.

1878. Elwin, Charles, London County Council, Spring Gardens, London, S.W.

1890. English, Lt.-Colonel Thomas, Palmer's Ordnance Works, Jarrow: (or care of W. Stamm, 39 Victoria Street, Westminster, S.W.)

1885. Errington, William, Salisbury Buildings, Bourke Street, Melbourne, Victoria.

1891. Esson, David Duncan, 47 Kennington Oval, London, S.E.

1890. Esson, John, Messrs. Blaikie Brothers, Footdee Iron Works, Aberdeen.

1889. Etches, Harry, Waterous Engine Works Co., Brantford, Ontario, Canada.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Messrs. Bolckow Vaughan and Co., Cleveland Iron and Steel Works, South Bank, R.S.O., Yorkshire.

1888. Evans, Joseph, Culwell Foundry, Wolverhampton.

1892. Evanson, Frederic Macdonnell, Manchester Corporation Hydraulic Pumping Station, Gloucester Street, Manchester.

1887. Everard, John Breedon, 6 Millstone Lane, Leicester.

1887. Everitt, Nevill Henry, Messrs. Thomas Piggott and Co., Atlas Works, Birmingham; and Ardendale, Knowle, Warwickshire.

1881. Ewen, Thomas Buttwell, Messrs. Ewen and Mitton, Smithfield Works, Sherlock Street, Birmingham.

1891. Ewing, James Alfred, F.R.S., Professor of Mechanism and Applied Mechanics, Engineering Department, The University, Cambridge; and Langdale Lodge, Cambridge.

1890. Exton, George Gaskell, Messrs. Chubb and Son, 128 Queen Victoria Street, London, E.C.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and care of Messrs. F. A. Robinson and Co., 69 Cornhill, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1882. Feeny, Victor Isidore, 60 Queen Victoria Street, London, E.C. [*Victor Feeny, London.*]

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1877. Fenton, James, Passlands, 278 Upper Richmond Road, Putney, London, S.W.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E. [*Clennell, London.*]

1892. Fenwick, James, 19 Bridge Street, Sydney, New South Wales. [1038.]

1870. Ferguson, Henry Tanner, Wolleigh, Bovey Tracey, near Newton Abbot.

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1866. Fiddes, Walter, Clapton Villa, Belgrave Road, Tyndall's Park, Bristol.

1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1888. Field, Howard, Messrs. John Bell and Son, 118A Southwark Street, London, S.E.; and Hillcote, Buckhurst Hill, S.O., Essex.

1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1891. Finlayson, Finlay, East End Villa, Lugar Street, Coatbridge.

1891. Firth, George Henry, Clayton Foundry, Clayton, Manchester.

1888. Fischer, Gustave Joseph, Tramway Construction Branch, Public Works Department, Beresford Chambers, Castlereagh Street, Sydney, New South Wales.

1889. Fisher, Henry Bedwell, Locomotive Works, London Brighton and South Coast Railway, Brighton.

1884. Fisher, Henry Oakden, Ty Mynydd, Radyr, near Cardiff.

1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C. [2283.]

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users', Manchester.*]

1892. Focken, Charles Frederick, Messrs. Apcar and Co., Raddah Bazar, Calcutta, India; and care of Institute of Engineers and Shipbuilders, Hong Kong, China.

1859. Fogg, Robert, 159 Knight's Hill, West Norwood, London, S.E.

1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.

1886. Folger, William Mayhew, Commander, United States Navy, Bureau of Ordnance, Naval Department, Washington, D.C., United States.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Bombay.

1892. Forbes, Percy Alexander, Messrs. Lambert Brothers, Tube Mills, Iron and Brass Works, Walsall.

1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1892. Forrest, Hilary Sheldon, General Manager, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.

1888. Forster, Edward John, Malta Villa, West Smethwick, Birmingham.

1882. Forsyth, Robert Alexander, Courtway, Gold Tops, Newport, Monmouthshire.

1889. Foster, Ernest Howard, Messrs. Henry R. Worthington, 86 Liberty Street, New York, United States.

1886. Foster, Frederick, Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N. [*Drinks, London.* 306.]

1889. Foster, Herbert Anderton (*Life Member*), Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1888. Foster, James, Lily Bank, St. Andrew's Drive, Pollokshields, Glasgow.

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Consulting Engineer, Dock Office, West Hartlepool; and 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Manager, Glasgow Corporation Gas Department, City Chambers, 45 John Street, Glasgow.

1885. Fourny, Hector Foster, French Chambers, Queen's Dock-Side, Hull. [*Veritas, Hull.*]

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, Bart., K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1885. Fowler, William Henry, 6 Victoria Station Approach, Manchester; and The Poplars, New Moston, near Manchester.

1866. Fox, Sir Douglas, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1888. Francken, William Augustus, care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Goldsbrough Mort and Co., 149 Leadenhall Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. John Fraser and Son, Millwall Boiler Works, London, E.; and 110 Cannon Street, London, E.C.

1888. Frenzel, Arthur Benjamin, 93 Liberty Street, New York, United States.

1891. Frier, John Drummond, Penlee, 61 Wrottesley Road, Plumstead.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Barnsley Road, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1891. Fuller, Charles Frederick, 171 Queen Victoria Street, London, E.C.

1884. Furness, Edward, Knollcroft, Knoll Road, Bexley, S.O., Kent.

1890. Gadd, William, Assistant Locomotive Engineer, Waterford and Limerick Railway, Limerick.

1866. Galloway, Charles John, Managing Director, Messrs. Galloways, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. Galton, Sir Douglas, K.C.B., D.C.L., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1884. Ganga Ram, Rai Bahadur, Executive Engineer, Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Thomas Wilson and Co., 24 Rood Lane, London, E.C.)

1891. Garrard, Charles Riley, Abingdon Works, Bath Street, Birmingham.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1888. Gaze, Edward Henry James, 4 Victoria Drive, Mount Florida, Glasgow.

1888. Geddes, Christopher, 23 Brunswick Street, Liverpool.

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]

1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.; and 30 South Street, Greenwich, London, S.E.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1883. Gilchrist, Percy Carlyle, F.R.S. (*Life Member*), Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London*]; and Frognal Bank, Finchley New Road, Hampstead, London, N.W.

1856. Gilkes, Edgar, Westholme, Grange-over-Sands, viâ Carnforth, Lancashire.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1889. Gill, Frederick Henry, Messrs. Alexander Penney and Co., 107 Fenchurch Street, London, E.C.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1887. Gledhill, Manassah, Sir Joseph Whitworth and Co., Openshaw, Manchester.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.

1882. Goldsmith, Alfred Joseph, Lillington, Moray Street, New Farm, Brisbane, Queensland.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1884. Goodger, Walter William, 34 Dairy House Road, Derby.

1890. Goodman, John, Professor of Engineering, Yorkshire College, Leeds.

1885. Goodwin, Arnold, Jun., 56 Sumner Street, Southwark, London, S.E.

1889. Goold, William Tom, 39 Queen Victoria Street, London, E.C.; and The Glen, Gorst Road, Wandsworth Common, London, S.W.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 118 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1875. Gordon, Robert, 8 St. Mary Street, St. Andrews.

1888. Gore, Arthur Saunders, Sherborne Metal Works, Sherborne Street, Birmingham.

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1887. Gourlay, Charles Gershom, Messrs. Gourlay Brothers and Co., Dundee Foundry, Dundee.

1890. Grace, Robert William, Colorado Fuel and Iron Co., Pueblo, Colorado, United States.

1878. Grafton, Alexander, Vulcan Works, Bedford. [*Grafton, Bedford.*]

1886. Grant, Percy, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic: (or care of John M. Grant, 136 Sutherland Avenue, Maida Vale, London, W.)

1891. Gray, George Macfarlane (*Life Member*), Imperial Chinese Customs, Hong Kong, China.

1865. Gray, John Macfarlane, Chief Examiner of Engineers, Marine Department, Board of Trade, 79 Mark Lane, London, E.C.; and 1 Claremont Road, Forest Gate, London, E. [*Yarg, London.*]

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and 24 St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 15 Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1888. Green, Henry Joseph Kersting, Messrs. Barry and Co., 5 Lyons Range, Calcutta, India; 13 Garden Reach, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1893. Green, William Penrose, Messrs. Thomas Green and Son, Smithfield Iron Works, Leeds.

1871. Greener, John Henry, 15 Walbrook, London, E.C.

1890. Greening, William Alfred, Steam Loop Co., 1 Leadenhall Street, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Birmingham Small Arms and Metal Co., Adderley Park Works, Birmingham.

1879. Grenville, Robert Neville, Butleigh Court, Glastonbury.

1892. Gresham, Harry Edward, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Salford, Manchester. [*Brake, Manchester.* 613.]

1883. Grew, Frederick, Halton, 90 Ritherdon Road, Upper Tooting, London, S.W.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1884. Griffiths, James E., Messrs. Griffiths and James, 2 Bute Crescent, Cardiff.

1873. Griffiths, John Alfred, Shirecliffe, New South Head Road, Sydney, New South Wales: (or care of Thomas Griffiths, Alderley Edge, Manchester.)

1889. Grimshaw, James Walter, Resident Engineer, Harbours and Rivers Department, Sydney, New South Wales; and Australian Club, Sydney, New South Wales.

1891. Groom, Richard Alfred, Shropshire Works, Wellington, Salop.

1879. Grose, Arthur, Messrs. Grose Norman and Co., Reliance Works, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham. [*Cowen, Nottingham.* 87.]

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1886. Guy, Charles Williams, 123 Oakfield Road, Penge, London, S.E.

1870. Gwynne, James Eglinton Anderson (*Life Member*), Brooke Street Works, Holborn, London, E.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.; and 89 Cannon Street, London, E.C.

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield. [*Hadfield, Sheffield.*]

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 111 Federal Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1892. Hall, George Edward, Mechanical Superintendent, Lighting Department, Salford Corporation, Wilburn Street, Salford, Manchester.

1879. Hall, John Francis, Norbury, Pittsmoor, Sheffield.

1881. Hall, John Percy, Managing Director, Messrs. John Penn and Sons, Greenwich, London, S.E.

1882. Hall, John Willim, Ivy House, Bilston.

1890. Hall, Oscar Standring, Messrs. Robert Hall and Son's, Hope Foundry, Bury.

1874. Hall, Thomas Bernard, 119 Colmore Row, Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, Messrs. Takata and Co., Ginza San Chome 18, Banchi, Tokio, Japan; and 88 Bishopsgate Street Within, London, E.C.

1889. Hall-Brown, Ebenezer, Messrs. Hall-Brown Buttery and Co., Helen Street Engine Works, Govan, Glasgow. [*Triple, Glasgow.* 1843.]

1880. Hallett, John Harry, 123 Bute Street, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* 3075, care of Victoria Chambers Co.]

1875. Hammond, Walter John, The Grange, Knockholt, near Sevenoaks.

1886. Hanbury, John James, Edgeley, Walm Lane, Willesden Park, London, N.W.

1870. Hannah, Joseph Edward, Castle View, Carlisle.

1892. Hansell, Robert Blackwell, Baltimore, Maryland, United States: (or care of James Hansell, 62 Jerningham Road, New Cross, London, S.E.)

1888. Harada, Torazo, Superintending Engineer, Osaka Shipping Co., Osaka, Japan.

1891. Harcourt, Otto Simon Henry, Clarence Iron Works, Leeds.

1888. Harding, Thomas Walter, Tower Works, Leeds.

1874. Harding, William Bishop, IX Ker. Rakos utcza 5 ik. sz., 1sö. Emelet, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1887. Hargraves, Richard, 3 London Road, Blackburn.

1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1888. Harker, William, Messrs. Richard Schram and Co., 17A Great George Street, Westminster, S.W.

1888. Harland, Sir Edward James, Bart., M.P., Messrs. Harland and Wolff, Belfast; and Baroda House, Kensington Palace Gardens, London, W.

1891. Harris, Gordon, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.

1879. Harris, Henry Graham, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1885. Harris, John Henry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C. [*Tuneharp, London.*]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1892. Harrison, Abraham Wyke, Lion Street, Abergavenny.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1888. Harrison, George, 21 Hillsboro Road, East Dulwich, London, S.E.

1889. Harrison, Gilbert Harwood, Lieutenant R.E., care of Albert à Beckett, 6 Brompton Square, London, S.W.

1885. Harrison, Joseph, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1891. Harrison, Joseph Hutchinson, Messrs. Howson and Harrison, 2 Exchange Place, Middlesbrough; and Clifford Villa, Coatham, Redcar.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 78 Queen Victoria Street, London, E.C.

1890. Harrison, William Robert, Manager, Hull Cart and Wagon Co., Newington Iron Works, Hull.

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 28 Victoria Street, Westminster, S.W.)

1882. Hart, Norman, 68 Inderwick Road, Stroud Green, London, N.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1892. Harvey, Edward Cartwright, Engineer, Geldenhuis Estate and Gold Mining Co., P. O. Box 1022, Johannesburg, Transvaal, South Africa.

1892. Harvey, Francis Haniel, Messrs. Harvey and Co., Hayle Foundry, Hayle, Cornwall.

1886. Harvey, John Boyd, North's Navigation Collieries, Tondû, near Bridgend, Glamorganshire.

1883. Harvey, Robert, 1 Palace Gate, London, W.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1881. Haslam, Sir Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, Waterside, Ferry Road, Teddington, S.O., Middlesex.

1892. Hawkins, Rupert Skelton, Locomotive and Carriage Department, Indian Midland Railway, Jhansi, India.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1891. Hawksley, George William, Brightside Boiler and Engine Works, Savile Street East, Sheffield. [*Hawksley, Sheffield.* 337.]

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, 55 Steep Hill, Lincoln.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1885. Head, Archibald Potter, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London*, 3237.]; and Queen's Square, Middlesbrough.

1888. Head, Harold Ellershaw, 24 Auriol Road, West Kensington, London, W.

1869. Head, Jeremiah, Messrs. Jeremiah Head and Son, 47 Victoria Street, Westminster, S.W. [*Principium, London.* 3237.]; and Queen's Square, Middlesbrough.

1857. Healey, Edward Charles, 33 Norfolk Street, Strand, London, W.C.

1890. Heap, Ray Douglas Theodore, Messrs. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and 37 Sinclair Road, Kensington, London, W.

1872. Heap, William, 9 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]

1889. Heath, George Wilson, Messrs. Heath and Co., Observatory Works, Crayford, Kent.

1888. Heatly, Harry, Messrs. Heatly and Gresham, 7 Hastings Street, Calcutta, India. [*Brake, Calcutta.*]

1875. Heenan, Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester; and The Manor House, Wilmslow, near Manchester. [*Spherical, Newton Heath.*]

1879. Hele-Shaw, Henry Selby, Professor of Engineering, University College, Liverpool.

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1891. Henderson, Thomas, 6 and 8 Trueman Street, Liverpool.

1883. Henderson, William, P.O. Box 1933, Johannesburg, Transvaal, South Africa.

1888. Henning, Gustavus Charles, 726 Temple Court, 5 Beekman Street, New York, United States.

1879. Henriques, Cecil Quixam, Messrs. John H. Wilson and Co., Sandhills, Liverpool. [*Engineers, Liverpool.*]

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1891. Hepburn, Thomas, Officiating Chief Mechanical Engineer, Small Arms Ammunition Factory, Kirkee, Poona, India.

1892. Herbert, Alfred, Machine-Tool Works, Coventry. [*Lathe, Coventry.* 52.]

1893. Herbert, Charles, 35 Queen Victoria Street, London, E.C. [*Mancunian, London.*]

1893. Herbert, George Henry, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1884. Hernu, Arthur Henry, 69 Victoria Street, Westminster, S.W.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1887. Hibbert, George, Hibbert's Works, Bank Road, Gateshead.

1871. Hick, John, Mytton Hall, Whalley, near Blackburn.

1885. Hicken, Thomas, 1519 Calle Brandzen, Barraccas al Norte, Buenos Aires, Argentine Republic: (or care of Miss Hicken, Bourton, near Rugby.)

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1889. Hill, Arthur Ripley, Messrs. Hill Brothers, Nevins Foundry, Hunslet, Leeds.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1890. Hiller, Edward George, Chief Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1882. Hiller, Henry, Consulting Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester; and Athelney, Stanley Road, Alexandra Park, Manchester.

1873. Hilton, Franklin, General Manager, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1887. Hindson, William, South Shore Engineering Works, Gateshead. [*Hindson, Gateshead.*]

1891. Hodge, Arthur, Trewirgie, Redruth.

1891. Hodges, Frank Grattidge, Locomotive Department, Midland Railway, Burton-on-Trent.

1870. Hodges, Petronius, 142 Burngreave Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]

1889. Hodgson, George Herbert, Thornton Road, Bradford.

1892. Hodgson, Henry Edwin, Brookhouse Iron Works, Cleckheaton, S.O., Yorkshire.

1891. Hogarth, Thomas Oswald, Great Western Railway Works, Swindon.

1889. Hoggins, Alfred Farquharson, Brush Electrical Engineering Co., Albert Buildings, 49 Queen Victoria Street, London, E.C.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1884. Holland, Calvert Bernard, Hazel Villa, Thicket Road, Anerley, London, S.E.

1886. Hollis, Charles William, Messrs. Claringburn and Co., Liverpool Street, Nottingham.

1885. Hollis, Henry William, Whitworth House, Spennymoor.

1891. Holman, Hugh Wilson, Messrs. E. J. Caiger and Co., 77 Billiter Buildings, Billiter Street, London, E.C. [*Caiger, London.*]

1892. Holmström, Carl Albert, Maxim-Nordenfelt Guns and Ammuntion Co., 32 Victoria Street, Westminster, S.W.

1883. Holroyd, John, 133 Croxted Road, West Dulwich, London, S.E.

1863. Holt, Francis, Locomotive Department, Midland Railway, Derby.

1873. Holt, Henry Percy, The Cedars, Didsbury, Manchester.

1890. Holt, Robert, Professor of Engineering, The People's Palace Technical Schools, Mile End Road, London, E.

1890. Holt, William Procter, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1888. Homan, Harold, Messrs. Homan and Rodgers, 10 Marsden Street, Manchester. [*Namoh, Manchester.* 637.]

1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.

1890. Hooker, Benjamin, Pear Tree Court, Farringdon Road. London, E.C.

1892. Hope, John Basil, Locomotive Department, North Eastern Railway, Leeds.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham; and 5 Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1890. Hopper, Allan, Messrs. William Hopper and Co., Moscow, Russia.

1890. Hopper, James Russell, Messrs. William Hopper and Co., Moscow, Russia.

1889. Hopwood, John, Locomotive Superintendent, Argentine Great Western Railway, Mendoza, Argentine Republic.

1891. Hornbrook, Raymond Hillman, Imperial Revenue Cutter "Fei Hoo," care of Imperial Maritime Customs, Shanghai, China.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1889. Horsfield, Cooper, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1891. Horsfield, Ralph, Messrs. Kirk and Horsfield, Chapel-en-le-Frith, near Stockport.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1892. Horsnell, Daniel, 79 Farringdon Road, London, E.C.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, 4 Cedars Road, Clapham Common, London, S.W.

1886. Hosgood, John Howell, Locomotive and Hydraulic Superintendent, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Richard, Severn Tunnel Works, Sudbrook, near Chepstow.

1873. Hoskin, Richard, 8 Norfolk Street, Sheffield.

1888. Hosking, Thomas, Messrs. T. and J. Hosking, Dockhead Iron Works, 53 Parker's Row, Bermondsey, London, S.E.

1892. Houghton, Francis Gassiot, 17 Victoria Street, Westminster, S.W.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1889. Houghton, Thomas Harry, 58 Pitt Street, Sydney, New South Wales: (or care of Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.) [*Expansion, Sydney.*]

1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.

1891. How, William Field, Mutual Life Buildings, George Street, Sydney, New South Wales. [*Alaska, Sydney.*]

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1879. Howard, James Harold, Britannia Iron Works, Bedford; and Kempston Grange, Bedford.

1882. Howard, John William, 78 Queen Victoria Street, London, E.C.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1892. Howitt, James John, Messrs. Bowman Thompson and Co., Lostock Gralam, Northwich.

1882. Howl, Edmund, Messrs. Lee Howl and Co, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1891. Hoy, Henry Albert, Locomotive Works, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1891. Hubback, Charles Arbuthnot, 9 Church Crescent, St. Albans.

1882. Hudson, John George, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton; and Glenholme, Bromley Cross, Bolton.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1893. Hudson, William, Ahmedabad, Bombay, India.

1881. Hughes, Edward William Mackenzie, 33 Renfield Street, Glasgow; and Ericstane, Helensburgh.

1867. Hughes, George Douglas, Messrs. G. D. Hughes and Son, Queen's Foundry, London Road, Nottingham.

1889. Hughes, John, Messrs. Hughes and Lancaster, 47 Victoria Street, Westminster, S.W.

1871. Hughes, Joseph, Kingston, Wareham.

1891. Hughes, Robert M., Folkestone Technical School, Folkestone.

1892. Hullah, Arthur, Victoria Jubilee Technical Institute, Byculla, Bombay, India: (or care of Walter Hunter, 12 Chetwynd Terrace, Meadow Road, Leeds.)

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1890. Humphries, Edward Thomas, Messrs. Edward Humphries and Co., Atlas Iron Works, Pershore.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, Albion Iron Works, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Egerton Mount, Heaton Chapel, R.O., Stockport.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1889. Hunter, Charles Lafayette, Engineer, Bute Docks, Cardiff.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1888. Huxley, George, 20 Mount Street, Manchester.

1885. Hyland, John Frank, Railway Contractor, São Carlos do Pinhal, Estado de São Paulo, Brazil: (or care of Messrs. Lewis and Hyland, New Rents, Ashford, Kent.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, Assistant Engineer, National Boiler Insurance Co., 22 St. Ann's Square, Manchester.

1888. Ingleby, Joseph, 20 Mount Street, Manchester.

1883. Instone, Thomas, 146 Leadenhall House, Leadenhall Street, London, E.C.

1892. Irons, Thomas, Manager, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, New South Wales.

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1887. Ivatts, Lionel Edward, Paseo Salamanca, F 2° Derecha, San Sebastian, Spain.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and Woodgreen, Wednesbury.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1873. Jackson, Samuel, C.I.E., care of E. Jackson, Beltwood, Ranmoor, Sheffield.

1886. Jackson, Thomas, 41 Wesley Road, Armley, Leeds.

1889. Jackson, William, Thorn Grove, Mannofield, Aberdeen.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1893. James, Arthur William, Superintending Engineer, Calcutta Steam Navigation Co.; care of Messrs. Hoare Miller and Co., 38 Strand Road, Calcutta, India.

1889. James, Charles William, Wheathill Lodge, Anerley, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 28 Victoria Street, Westminster, S.W.

1889. James, Reginald William, 1 Queen Victoria Street, London, E.C.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1888. Jaques, Lieut. William Henry, Secretary to Ordnance Committee, United States; and South Bethlehem, Pennsylvania, United States.

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1877. Jeffreys, Edward Homer, Hawkhills, Chapel Allerton, Leeds.

1893. Jenkin, Charles Frewen, Messrs. Nettlefolds, Castle Works, Tydu, near Newport, Monmouthshire.

1884. Jenkins, Alfred, Wharncliffe, Victoria Road, Penarth.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Jenkins, William John, Albion Iron Works, Miles Platting, Manchester.

1893. Jennins, Henry Horwood, care of Edwin Oldroyd, Crown Works, Crown Street, Leeds.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1889. Jessop, George, London and Leicester Steam-Crane and Engine Works, Leicester.

1886. Jewell, Henry William, Messrs. Jewell and Son, City Foundry, Winchester.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 9 Upper Northgate Street, Chester.

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1890. Johnson, John William, care of Baron Knoop, Grande Loubianka, Moscow, Russia.

1891. Johnson, Lacey Robert, Master Mechanic, Pacific Division, Canadian Pacific Railway, Vancouver, British Columbia.

1888. Johnson, Lawrence Potter, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.; and The Warren Hill, Loughton, Essex.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1891. Johnston, Andrew, Bank Buildings, Hong Kong, China. [*Marine, Hong Kong.*]

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1891. Jones, Charles Frederick, Messrs. Greaves Cotton and Co., Empress Mill, Delisle Road, Parel, Bombay, India.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Kirkstall, Aldridge Road, Perry Barr, Birmingham.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, District Locomotive Superintendent, North Western Railway, Multan, Punjaub, India: (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1890. Jones, Morlais Glasfryn, 6 Delahay Street, Westminster, S.W.

1882. Jones, Samuel Gilbert, Hatherley Court, Gloucester.

1887. Jones, Thomas, Central Board School, Deansgate, Manchester.

1872. Jones, William Richard Sumption, Whitehall Court, London, S.W.

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1891. Jordan, Henry George, Jun., Municipal Technical School, Princess Street, Manchester.

1880. Joy, David, 17 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1891. Judd, Joseph Henry, Head Master, Technical and Manual Instruction School, York Place, Brighton.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 2504.]

1889. Kanthack, Ralph, 21 Golden Square, Regent Street, London, W. [*Kanthack, London.*]

1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.

1882. Keeling, Herbert Howard, Merlewood, Eltham.

1869. Keen, Arthur, London Works, near Birmingham. [*Globe, Birmingham.*]

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Westbromwich.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Darlington.

1879. Kennedy, Professor Alexander Blackie William, F.R.S., 14 Old Queen Street, Westminster, S.W. [*Kinematic, London.*]

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1892. Kennedy, Thomas, The Glenfield Engineering Works, Kilmarnock.

1868. Kennedy, Thomas Stuart, Parkhill, Wetherby.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1892. Kensington, Frederick, 2 Copthall Buildings, London, E.C.

1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1890. Key, George Andrew, General Manager, Wallsend Pontoon Works, Bute Docks, Cardiff.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic: (or care of J. R. H. Keyworth, 28 Grosvenor Road, Birkenhead.)

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1893. Kinghorn, John Warden, care of Messrs. Jardine Matheson and Co., Hong Kong, China.

1889. Kirby, Frank Eugene, Constructing Engineer, Detroit Dry Dock Co., Detroit, Michigan, United States.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Commissioner of Customs, Kowloon, Hong Kong, China: (or Melita Cottage, Denny.)

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1889. Knap, Conrad, 11 Queen Victoria Street, London, E.C.

1891. Knight, Bertrand Thornton, Engineer, Royal Siamese State Railways, Bangkok, Siam: (or care of Major Knight, Swansea.)

1886. Knight, Charles Albert, Babcock and Wilcox Boiler Co., 107 Hope Street, Glasgow.

1890. Knight, James Percy, Messrs. A. W. Robertson and Co., Custom House Engine Works, Victoria Docks, London, E.

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead. [*Laird, Birkenhead.* 4003.]

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead. [*Laird, Birkenhead.* 4003.]

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1878. Lambourn, Thomas William, Naughton Hall, near Bildeston, S.O., Suffolk.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of T. C. Langdon, Tamar Terrace, Launceston.)

1881. Lange, Frederick Montague Townshend, 21 Rue Wissocq, Boulogne-sur-mer, France.

1893. Langford, William, Messrs. W. M. Ward and Co., Limerick Foundry, Great Bridge, Tipton.

1879. Langley, Alfred Andrew, 33 Chester Terrace, Regent's Park, London, N.W.

1879. Lapage, Richard Herbert, Elmwood, Surbiton, London, S.W.

1890. Last, Arthur John, Oulton, Abbeville Road, Balham, London, S.W.

1888. Latham, Baldwin, 13 Victoria Street, Westminster, S.W.; and Duppas House, Old Town, Croydon.

1890. Laurie, Leonard George, Mill Parade, Newport, Monmouthshire.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1893. Lawrie, James, Assistant Government Marine Surveyor, Singapore, Straits Settlements: (or 113 Alma Road, Sheerness.)

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Daniel Layborn and Co., Dutton Street, Liverpool.

1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1892. Lea, Richard Henry, Manager, Messrs. Singer and Co.'s Cycle Works, Coventry.

1889. Leaf, Henry Meredith, Burlington Lodge, Streatham Common, London, S.W.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1890. Ledingham, John Machray, Royal Laboratory, Royal Arsenal, Woolwich.

1887. Lee, Cuthbert Ridley, Messrs. J. Coates and Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1862. Lee, J. C. Frank, 9 Park Crescent, Portland Place, London, W.

1892. Lee, Richard John, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1890. Lee, Samuel Edward, Messrs. Harrison Lee and Sons, City Foundry, Limerick.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1889. Legros, Lucien Alphonse, 57 Brook Green, Hammersmith, London, W.

1883. Lennox, John, 28 Victoria Street, Westminster, S.W.

1858. Leslie, Andrew, Coxlodge Hall, Newcastle-on-Tyne.

1888. Leslie, Sir Bradford, K.C.I.E., Tarrangower, Willesden Lane, Brondesbury, London, N.W.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

1888. Letchford, Joseph, Manager, Messrs. David Munro and Co., Stuart Street, Melbourne, Victoria; care of Richard Speight, Glenroy Park, Hampton Street, Middle Brighton, Melbourne, Victoria: (or care of James Letchford, 370 Wandsworth Road, London, S.W.)

1878. Lewis, Gilbert, 538 Eccles New Road, Eccles, Manchester.

1884. Lewis, Henry Watkin, Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1891. Lindsay, William Robertson, Messrs. W. B. Thompson and Co., Lilybank Engine Works, Dundee.

1890. Lineham, Wilfrid James, Professor of Engineering and Mechanical Science, The Goldsmiths' Institute, New Cross, London, S.E.; and Jesmond, Leyland Road, Lee, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.; and 3 St. John's Park, Blackheath, London, S.E.

1885. Lister, Frank, Messrs. Lister and Co., Beechcliffe, Keighley; and Oaklands, Keighley.

1890. Lister, Robert Ramsbottom, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and 23 Park Road, Southport.

1890. Livens, Frederick Howard, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Royal College of Science, Exhibition Road, South Kensington, London, S.W.

1867. Lloyd, Charles, National Conservative Club, 9 Pall Mall, London, S.W.

1871. Lloyd, Francis Henry, James Bridge Steel Works, near Wednesbury [*Steel, Wednesbury*]; and Stowe Hill, Lichfield.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1890. Locke, Arthur Guy Neville, Leadenhall Chambers, 4 St. Mary Axe, London, E.C.

1879. Lockhart, William Stronach, 5 Haddo Villas, Blackheath, London, S.E.

1884. Logan, Andrew Linton, Railway Signal Works, Worcester.

1890. Logan, John Walker, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester; and Rand Club, Johannesburg, Transvaal, South Africa.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, care of Messrs. Finlay Muir and Co., Calcutta, India: (or Moatville, Charleville, County Cork, Ireland.)

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1888. Low, David Allan, Lecturer on Engineering, The People's Palace Technical Schools, Mile End Road, London, E.

1861. Low, George, Bishop's Hill Cottage, Ipswich.

1885. Low, Robert, Powis Lodge, Vicarage Park, Plumstead.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, General Manager, Barry Graving Dock and Engineering Co., Exchange Buildings, Cardiff. [*Bardock, Cardiff.*]

1891. Lowdon, Thomas, Kingsland Crescent, Barry Docks, B.O., near Cardiff.

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1873. Lucas, Arthur, 27 Bruton Street, New Bond Street, London, W.

1889. Lucy, Arthur John, Messrs. Turner Morrison and Co., Sugar Works, Cossipore, Calcutta, India.

1886. Lucy, William Theodore, care of Frank Hudson, Central Uruguay Railway, Monte Video, Uruguay: (or Thornleigh, Woodstock Road, Oxford.)

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1887. Lupton, Kenneth, Messrs. K. and H. Lupton, Vulcan Works, Burgess, Coventry.

1878. Lynde, James Henry, Buckland, Ashton-on-Mersey, near Manchester.

1889. Macallan, George, Works Manager, Great Eastern Railway, Stratford Works, London, E.

1890. Macan, Richard Thompson, Dawlish House, Willesden, London, N.W.

1892. Macbean, John James, Messrs. Howarth Erskine and Co., Singapore, Straits Settlements.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1890. MacBrair, William Maxwell, 34 Crookes Road, Sheffield.

1884. MacCarthy, Samuel, Messrs. Lloyd and Lloyd, 90 Cannon Street, London, E.C.; and 18 Adelaide Road, Brockley, London, S.E.

1877. MacColl, Hector, Strandtown, Belfast.

1879. Macdonald, Augustus Van Zundt, Locomotive Engineer, Addington, Christchurch, New Zealand.

1889. Macdonald, James Alexander, Broad Oaks Iron Works, Chesterfield.

1892. Machado, Dr. Antonio Augusto, Manager, Companhia Metropolitana, Engineering and Boiler Works, Bahia, Brazil: (or care of Messrs. Heuser Humble and Co., 1 Fowkes Buildings, Great Tower Street, London, E.C.)

1892. Mackay, Charles O'Keefe, Locomotive Department, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1890. Mackay, Joseph, Bangkok Dock Co., Bangkok, Siam: (or care of Messrs. John Birch and Co., 10 Queen Street Place, London, E.C.) [*Mackay, Bangkok.*]

1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 40 Chancery Lane, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1875. Maclagan, Robert, care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.

1889. MacLay, Alexander, Professor of Mechanical Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock; and 31 Bank Street, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1888. Macleod, Arthur William, Schwebo Mining Syndicate, Kyouk Myoung Post Office, Upper Burmah.

1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokyo, Japan.

1865. Macnee, Daniel, 3 Victoria Street, Westminster, S.W. [*Macnee, London.*]; and Rotherham.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1892. Mactear, James, F.R.S.E., 28 Victoria Street, Westminster, S.W. [*Celestine, London.* 3066.]

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*James Maginnis, London;* and *Offsett, London.*]

1891. Mahon, Reginald Henry, Captain R.A., Superintendent, H. M. Shell Factory, Cossipore, Calcutta, India.

1873. Mair-Rumley, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1884. Mais, Henry Coathupe, 61 Queen Street, Melbourne, Victoria.

1883. Malan, Ernest de Mérindol, Signal and Telegraph Department, Hull Barnsley and West Riding Junction Railway and Dock Co., Alexandra Dock, Hull. [*Engineer, Deepdock, Hull. Nat.* 106.]

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1891. Manisty, Edward, Dundalk Iron Works, Dundalk, Ireland; and 24A Bryanston Square, London, W.

1888. Mano, Bunji, Professor of Mechanical Engineering, Imperial University, Tokyo, Japan.

1875. Mansergh, James, 5 Victoria Street, Westminster, S.W.

1891. Manson, James, Locomotive Superintendent, Glasgow and South Western Railway, Kilmarnock.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1878. Marié, Georges, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1891. Marks, Edward Charles Robert, 13 Temple Street, Birmingham.

1888. Marks, George Croydon, 13 Temple Street, Birmingham. [*Pumps, Birmingham.*]

1884. Marquand, Augustus John, 2 Dock Chambers, Bute Docks, Cardiff. [*Martial, Cardiff.*]

1887. Marriott, William, Engineer and Locomotive Superintendent, Midland and Great Northern Joint Railways, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Rev. Alfred (*Life Member*), The Vicarage, Feckenham, Redditch.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1890. Marshall, Frank Herbert, Ormesby Iron Works, Middlesbrough.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Messrs. Chance Brothers and Co., Glass Works, near Birmingham; and Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, Richmond Hill, Edgbaston, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Pedmore, Stourbridge. [*Marten, Stourbridge.* 8504.]

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1888. Martin, Henry James, Tresleigh House, Walters Road, Swansea.

1889. Martin, The Hon. James, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1892. Martin, Thomas George, Messrs. James McGowan and Co., Wapping Wall, London, E.

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Martindale, Warine Ben Hay, 38 Parliament Street, Westminster, S.W.; and Overfield, Bickley, R.S.O., Kent.

1882. Masefield, Robert, 14 Markham Square, Chelsea, London, S.W.

1884. Massey, George, Post Office Chambers, Pitt Street, Sydney, New South Wales.

1890. Massey, Stephen, Messrs. B. and S. Massey, Openshaw, Manchester.

1893. Massey, William Henry, 25 Queen Anne's Gate, Westminster, S.W.; and Twyford, R.S.O., Berkshire.

1892. Masterton, John Fraser, Locomotive Department, South Eastern Railway, Ashford, Kent.

1867. Mather, William, M.P., Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Queen Dyeing Co., Providence, Rhode Island, United States.

1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China: (or care of Messrs. Matheson and Grant, 13 Walbrook, London, E.C.)

1891. Mathewson, Jeremiah Eugene, Tilghman's Sand-Blast Co., Bellefield Works, Bellefield Lane, Sheffield.

1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.

1886. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1893. Maunsell, Richard Edward Lloyd, Locomotive Department, Lancashire and Yorkshire Railway, Fleetwood, R.S.O., Lancashire.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, Maxim Nordenfelt Guns and Ammunition Co., 32 Victoria Street, Westminster, S.W.

1859. Maylor, William, Chesterleigh, Albemarle Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1891. McCredie, Arthur Latimer, 250 Pitt Street, Sydney, New South Wales. [*Ebony, Sydney.* 63.]

1892. McDonald, John, Locomotive Works, Imperial Government Railways, Tokyo, Japan.

1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 28 Victoria Street, Westminster, S.W.; and The Cedars, Norwood Green, Southall.

1891. McFarlane, George, Bank of Scotland Buildings, 24 George Square, Glasgow. [*Asphodel, Glasgow.*]

1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C. [*Sahib, London.*]

1892. McGregor, Peter (*Life Member*), Imperial Maritime Customs, Kowloon, Hong Kong, China.

1892. McIntosh, William Forbes, Messrs. Douglas Lapraik and Co., Hong Kong, China.

1889. McIntyre, John Henry A., Lecturer on Mechanical Engineering, Allan Glen's School, Glasgow.

1881. McKay, John, 13 Grey Street, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 22 George Street, Hanover Square, London, W.

1888. McLarty, Farquhar Matheson, Penang Foundry, Penang: (or care of William Bow, Thistle Engine Works, Paisley.) [*McLarty, Penang.*]

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Glasgow.*]

1891. Meade, Thomas de Courcy, Engineer, Hornsey District Board, 99 Southwood Lane, Highgate, London, N. [*Umpireship, London.* 7581.]

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1881. Meik, Charles Scott, care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.

1858. Meik, Thomas, 21 York Place, Edinburgh.

1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1891. Melville, William Charles, Superintendent Engineer, Liverpool Steam Tug Co., 44 Chapel Street, Liverpool.

1888. Melville, William Wilkie, 284 Ivydale Road, Nunhead, London, S.E.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Co., 50 Side, Newcastle-on-Tyne. [*William Menzies, Newcastle-on-Tyne. G.P.O.* 200. *Nor. Dis.* 1144.]

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]

1891. Metcalfe, Frederick Spencer, Pumping Station, Sewage Works, Burton-on-Trent.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 17 Victoria Street, Westminster, S.W.

1891. Middleton, Robert, Sheepscar Foundry, Leeds.

1891. Middleton, Robert Thomas, Superintendent of Bridge Works, Bombay Baroda and Central India Railway, Bombay, India.

1886. Midelton, Thomas, Aylesbury, Albemarle Street, North Kingston, Sydney, New South Wales.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1887. Miles, Frederick Blumenthal, Messrs. Bement Miles and Co., Callowhill and Twenty-first Streets, Philadelphia, United States.

1893. Millar, Jackson, Messrs. Riley Hargreaves and Co., 11 Merchant Road, Singapore, Straits Settlements: (or care of J. R. Allan, 93 Hope Street, Glasgow.)

1889. Miller, Adam, 50 Lime Street, London, E.C.

1885. Miller, Harry William, New Chimes Gold Mining Co., P.O. Box 1083, Johannesburg, Transvaal, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1887. Miller, Thomas Lodwick, 7 Tower Buildings N., Water Street, Liverpool.

1893. Milligan, William Scott, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1893. Millington, Frederick Handel, Manager, Patent Pulp Manufacturing Co., Thetford; and Mill House, Thetford.

1885. Millis, Charles Thomas, Principal, Educational Department, Borough Road Polytechnic, London, S.E.

1887. Milne, William, The Oaks, 52 Queen Street, Durban, Natal.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1892. Mitcheson, George Arthur, Longton, Staffordshire. [*Mitcheson, Longton.* 445.]

1870. Moberly, Charles Henry, 13 Belmont Park, Lee, London, S.E.

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., The Manor House, Bexley, S.O., Kent.

1882. Molesworth, James Murray, Aberdeen House, Upper Holly Walk, Leamington.

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S.O., Kent.

1876. Moore, Joseph, 1099 Adeline Street, Oakland, San Francisco, California; 18 Upper Woburn Place, London, W.C.: (or care of Ralph Moore, Government Inspector of Mines, 13 Clairmont Gardens, Glasgow.)

1880. Moreland, Richard, Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1889. Morgan, David John, Merchants' Exchange, Cardiff.

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Morris, Charles, 5 Mangoe Lane, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1890. Morris, Francis Sanders, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1890. Morris, John Alfred (*Life Member*), Empire Works, 78 Great Bridgewater Street, Manchester.

1892. Morton, David Home, 95 Bath Street, Glasgow.

1858. Mountain, Charles George, 93 Hope Street, Glasgow.

1886. Mountain, William Charles, Messrs. Ernest Scott and Co., Close Works, Newcastle-on-Tyne; and 9 St. George's Terrace, Jesmond, Newcastle-on-Tyne.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Central Marine Engine Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 37 Brown Street, Manchester.

1876. Muirhead, Richard, Kentish Engineering Works, Maidstone. [*Muirhead, Maidstone.*]

1890. Müller, Henry Adolphus, Locomotive Superintendent, Municipal Railway, 3 North Road, Entally, Calcutta, India.

1890. Mumford, Charles Edward, St. Andrew's Works, Bury St. Edmunds.

1890. Munro, John, Merchant Venturers' Technical School, Unity Street, Bristol.

1890. Munro, Robert Douglas, Chief Engineer, Scottish Boiler Insurance and Engine Inspection Co., 13 Dundas Street, Glasgow.

1889. Münster, Bernard Adolph, Engineer, Yokohama, Japan.

1891. Murdoch, Robert Macmillan, Phœnix Metal Die and Engineering Co., 110 Stamford Street, Blackfriars, London, S.E.

1890. Murray, Alexander John, Chief Mechanical Engineer, Government Gun-Powder Factory, Kirkee, Bombay, India.

1890. Murray, Kenneth Sutherland, Brin's Oxygen Works, 69 Horseferry Road, Westminster, S.W.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1888. Myers, William Beswick (*Life Member*), 14 Victoria Street, Westminster, S.W.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1889. Nash, Thomas, Sheffield Testing Works, Blonk Street, Sheffield; and Guzerat House, Nether Edge, Sheffield.

1888. Nathan, Adolphus, Messrs. Larini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, 16 The Banks, High Street, Rochester.

1889. Needham, Joseph Edward, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Nelson, Arthur David, Hay and Lackey Streets, Sydney, New South Wales. [*Nelson, Sydney.* 160.]

1884. Nelson, John, Contractors' Office, Dringhouses, York.

1887. Nelson, Sidney Herbert, Messrs. Samuel Worssam and Co., Oakley Works, King's Road, Chelsea, London, S.W.

1881. Nesfield, Arthur, Messrs. Simpson Mackirdy and Co., 29 South Castle Street, Liverpool.

1882. Nettlefold, Hugh, Screw Works, 16 Broad Street, Birmingham. [*Nettlefolds, Birmingham.*]

1890. Newton, Percy, Vassall Lodge, Addison Road, Kensington, London, W.

1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways, Iquique, Chili.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1891. Nicholson, Thomas, Crownpoint Boiler Works, St. Marnock Street, Crownpoint Road, Glasgow.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 73 Clarence Street, Wynyard Square, Sydney, New South Wales.

1882. Nordenfelt, Thorsten, 8 Rue Auber, Paris.

1892. Norris, William, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1883. North, Gamble, Pisagua, Chile: (or care of B. Depledge, Woolpack Buildings, 3 Gracechurch Street, London, E.C.)

1891. North, George, 61 and 62 Gracechurch Street, London, E.C. [*Spero, London.*]

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; Woolpack Buildings, 3 Gracechurch Street, London, E.C.; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

1888. Norton, William Eardley, 8 Great George Street, Westminster, S.W.

1882. Nunneley, Thomas, Wanstead House, Burley, Leeds.

1885. Oakes, Sir Reginald Louis, Bart., Manager, La Métallurgique, La Sambre, Charleroi, Belgium.

1887. O'Brien, Benjamin Thompson, 45 Fern Grove, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1890. Ockendon, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. O'Connor, Charles, 15 Wesley Street, Waterloo, near Liverpool.

1888. O'Donnell, John Patrick, 70 and 71 Palace Chambers, 9 Bridge Street, Westminster, S.W.; and Avondale, College Road, Bromley, Kent. [*ODonnell, London.* 3059.]

1889. Ogden, Fred, Patent Office, 25 Southampton Buildings, London, W.C.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C. [*Oglio, London.* 2463.]

1893. Oke, Francis Robert, London and North Western Railway Works, Crewe.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C [*Oaktree, London.*]

1882. Orange, James, Messrs. Danby Leigh and Orange, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1889. Owen, Thomas, Midland Railway, Derby.

1868. Paget, Arthur, Loughborough. [*Paget Company, Loughborough.*]

1877. Panton, William Henry, Messrs. Dorman Long and Co., Middlesbrough.

1877. Park, John Carter, 68 Priory Road, West Hampstead, London, N.W.

1888. Parker, Thomas, Gorton House, Gorton, near Manchester.

1872. Parker, Thomas, Jun., Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester; and Gorton House, Gorton, near Manchester.

1891. Parker, Thomas, Chief Engineer, Electric Construction Corporation, Wolverhampton.

1879. Parker, William, 108 Fenchurch Street, London, E.C.; and Ash Dune, Catford Hill, London, S.E. [11053.]

1871. Parkes, Persehouse, Messrs. Persehouse Parkes and Co., 21 Drury Buildings, 21 Water Street, Liverpool. [*Fibrous, Liverpool.*]

1884. Parlane, William, Manager, Hong Kong Ice Company, Hong Kong, China.

1892. Parratt, William Heather, Enmore Plantation, East Coast, Demerara, British Guiana.

1892. Parrott, Thomas Henry, Messrs. G. E. Belliss and Co., Ledsam Street, Birmingham.

1886. Parry, Alfred, Messrs. Parry and Co., Vulcan Iron Works, Calcutta, India: (or care of Messrs. J. B. Barry and Son, 110 Cannon Street, London, E.C.)

1889. Parry, Evan Henry, Eagle Chambers, Adelaide Street, Swansea.

1878. Parsons, The Hon. Richard Clere, Messrs. Bateman Parsons and Bateman, 39 Victoria Street, Westminster, S.W. [*Outfall, London.* 3233]; and Oak Lea, Wimbledon Park, Surrey.

1886. Passmore, Frank Bailey, Mansion House Chambers, 11 Queen Victoria Street, London, E.C. [*Knarf, London.*]

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1891. Paton, Robert J., Companhia McHardy, Campinas, São Paulo, Brazil.

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1891. Pattison, Joseph, 123 Bute Street, Cardiff.

1891. Paul, Matthew, Jun., Messrs. Matthew Paul and Co., Levenford Works, Dumbarton.

1891. Paulson, Scott, Box 455, Johannesburg, Transvaal, South Africa: (or care of Dr. Paulson, Mountsorrel, near Loughborough.)

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, 87 East Hill, Colchester.

1890. Peacock, Francis, Locomotive Superintendent, Smyrna and Cassaba Railway, Smyrna, Asia Minor.

1890. Peacock, James Albert Wells, Assistant Locomotive Superintendent, Smyrna and Cassaba Railway, Smyrna, Asia Minor.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Pearce, George Cope, Ryefields, Ross.

1873. Pearce, Richard, Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.

1873. Penn, John, M.P., Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1879. Perkins, Stanhope, Healey Terrace, Fairfield, near Manchester.

1890. Perry, Weston Alcock, Phosphor-Bronze Co., Birmingham; and Kenwood, St. Peter's Road, Birmingham.

1893. Philip, William Littlejohn, Manager, Messrs. Spencer and Co., Melksham Foundry, Melksham.

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Henry Parnham, District Locomotive Superintendent, Eastern Bengal State Railway, Calcutta, India; and 71 Grosvenor Street, London, W.

1878. Phillips, John, 4 Corona Road, Burnt Ash Hill, Lee, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, Kimberley, South Africa; and care of H. Eckstein, Box 149, Johannesburg, Transvaal, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and Rochelle, Selhurst Road, South Norwood, London, S.E. [*Phicycle, London.*]

1890. Phillips, Walter, Messrs. Phillips and Cowell, 79 Mark Lane, London, E.C. [*Philology, London.* 11053.]

1882. Phipps, Christopher Edward, Locomotive Superintendent, Madras Railway, Perambore Works, Madras, India.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, 41 Upper Mount Street, Dublin.

1888. Pilkington, Herbert, Wellingborough Iron Works, Wellingborough.

1883. Pillow, Edward, 2 Carlton Terrace, Mill Hill Road, Norwich.

1892. Pinder, Charles Ralph, New Rietfontein Estate and Gold Mines, P. O. Box 661, Johannesburg, Transvaal, South Africa.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France. [*Lethuillier Pinel, Rouen.*]

1892. Pirie, George, 137 Maxey Road, Plumstead.

1882. Pirrie, John Sinclair, Austral Otis Elevator and Engineering Works, South Melbourne, Victoria: (or care of Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.)

1888. Pirrie, Norman, care of Messrs. Pirrie Hope and Co., Baltic Chambers, Newcastle-on-Tyne.

1888. Pirrie, William James, Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Linotype Co., 6 Serjeants' Inn, Fleet Street, London, E.C.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe (*Life Member*), Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John, Clydach Foundry, near Swansea.

1892. Pogson, Alfred Lee, Engineer-in-Chief, Harbour Trust Board and Works, Madras, India.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1893. Pollit, Edward Ernest, Messrs. Pollit and Wigzell, Bank Foundry, Sowerby Bridge.

1886. Pollock, James, 22 Billiter Street, London, E.C. [*Specific, London.*]

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool. [*Pooley, Liverpool.*]

1890. Potter, William Henry, Newcastle Chambers, Angel Row, Nottingham.

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 117 Camberwell Grove, London, S.E.

1878. Powel, Henry Coke, Tintern House, 64 Burnt Ash Hill, Lee, London, S.E.

1890. Powell, James Richard, Pierhead Chambers, Cardiff.

1874. Powell, Thomas, Brynteg, Neath.

1891. Powles, Henry Handley Pridham, Faraday House, Charing Cross Road, London, W.C.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1892. Pratt, Middleton, 6 Richmond Terrace, New Brighton, near Birkenhead.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1890. Preece, William Henry, F.R.S., General Post Office, St. Martin's-le-Grand, London, E.C.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 49 Queen Victoria Street, London, E.C. [*Indices, London.*]

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1890. Price, John, Inspecting Engineer, Workington.

1889. Price, John Bennett, Messrs. Charles Macintosh and Co., Cambridge Street, Manchester; and 13 Fishergate Hill, Preston.

1859. Price-Williams, Richard, 32 Victoria Street, Westminster, S.W. [*Spandrel, London.*]

1886. Price-Williams, Seymour William, 5 Victoria Street, Westminster, S.W.

1874. Prosser, William Henry, Messrs. Harfield and Co., Mansion House Buildings, 4 Queen Victoria Street, London, E.C.

1890. Pugh, Charles Henry, Whitworth Works, Rea Street South, Birmingham.

1887. Pullen, William Wade Fitzherbert, 100 Llandaff Road, Cardiff.

1884. Puplett, Samuel, 47 Victoria Street, Westminster, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1887. Pyne, Thomas Salter, care of H.H. the Ameer of Afghanistan, Kabul: (or care of E. C. Clarke, Foreign Office, Government of India, Simla or Calcutta, India: or care of Edmund Neel, C.I.E., India Office, Whitehall, London, S.W.)

1892. Quentrall, Thomas, H.M. Inspector of Mines, Kimberley, South Africa.

1893. Quirk, Edward, Chief Mechanical Engineer, Trinity House, London, E.C.

1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield. [*Radford, Sheffield.*]

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]

1885. Rainforth, William, Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]

1892. Ramsay, William, Superintendent Engineer, Scottish Oriental Steamship Co., Hong Kong, China.

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness; and Reform Chambers, 105 Pall Mall, London, S.W.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 32 Victoria Street, Westminster, S.W. [*Ransomes Rapier, Westminster.*]

1888. Rapley, Frederick Harvey, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1889. Ratcliffe, James Thomas, Baumwoll-Manufactur von Izr. K. Poznanski, Lodz, Russian Poland.

1883. Rathbone, Edgar Philip, Standard Bank Buildings, and P. O. Box 963, Johannesburg, Transvaal, South Africa. [*Viking, Johannesburg.*]

1867. Ratliffe, George, 7A Laurence Pountney Hill, London, E.C.

1893. Raven, Vincent Litchfield, Locomotive Department, North Eastern Railway, Gateshead.

1862. Ravenhill, John R., Delaford, Iver, near Uxbridge.

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham. [*Metro, Birmingham.*]

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Co., West Docks, South Shields.

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 64 Mark Lane, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1891. Reed, Thomas Alfred, 2 Bute Crescent, Cardiff.

1884. Rees, William Thomas, Mining Engineer, Gadlys Cottage, Aberdare.

1891. Reid, Hugh (*Life Member*), Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1889. Rendell, Alan Wood, Locomotive Superintendent, East Indian Railway, Jumalpur, Bengal, India: (or 21A Goldhurst Terrace, South Hampstead, London, N.W.)

1890. Rendell, Samuel, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and 306 Fairfield Road, Fairfield, near Manchester.

1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, 49 Queen's Gate, London, S.W.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1883. Reunert, Theodore, Box 209, Kimberley, South Africa; Box 92, Johannesburg, Transvaal, South Africa: (or care of Messrs. Findlay, Durham and Brodie, 43–46 Threadneedle Street, London, E.C.)

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Manager, Warora Colliery, Warora, Central Provinces, India.

1890. Rice, Thomas Sydney, Aldermary House, 60 Watling Street, London, E.C. [*Ricto, London.*]

1866. Richards, Edward Windsor, Low Moor Iron Works, near Bradford.

1882. Richards, George, Suffolk House, Laurence Pountney Hill, London, E.C.

1884. Richards, Lewis, 12 Park Villas, Llanishen, near Cardiff.

1863. Richardson, The Hon. Edward, C.M.G., Wellington, New Zealand.

1892. Richardson, Harry Alfred, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1891. Richardson, John Scott, 95 Millbrae Road, Langside, Glasgow: (or care of J. W. Champness Richardson, Lindum, 23 Coleridge Road, Crouch End, London, N.)

1887. Richardson, Thomas, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1889. Richmond, Joseph, New Sun Iron Works, Burdett Road, Bow, London, E.; and 30 Kirby Street, Hatton Garden, London, E.C.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Swalwell Steel Works, Newcastle-on-Tyne.

1893. Ridley, James Taylor, 6 Ruthin Gardens, Cardiff.

1887. Riekie, John, District Locomotive Superintendent, North Western Railway, Quetta, Beluchistan, India.

1874. Riley, James, General Manager, Steel Company of Scotland, 23 Royal Exchange Square, Glasgow.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1884. Ripper, William, Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1889. Riva, Enrico, Locomotive and Carriage Superintendent, Rete Adriatica, Ferrovie Meridionale, Florence, Italy.

1879. Rixom, Alfred John, 108 Park Road, Loughborough.

1891. Roberts, Hugh Jorwerth, Messrs. Burn and Co., Howrah Iron Works, Howrah, Calcutta, India: (or care of R. P. Roberts, 3 Osborne Road, Liscard, near Liverpool.)

1887. Roberts, Thomas, Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, 13 Craven Hill Gardens, Hyde Park, London, W.

1879. Robertson, William, Newlyn, Eton Avenue, Hampstead, London, N.W.

1890. Robinson, Frederick Arthur, Messrs. F. A. Robinson and Co., 69 Cornhill, London, E.C.

1874. Robinson, Henry, Professor of Civil Engineering, King's College, Strand, London, W.C.; and 13 Victoria Street, Westminster, S.W.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and Westwood Hall, Leek, near Stoke-upon-Trent.

1886. Robinson, John, 8 Vicarage Terrace, Kendal.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow.

1891. Robinson, John George, Locomotive and Carriage Engineer, Waterford and Limerick Railway, Limerick.

1892. Robinson, Leslie Stephen, 28 Victoria Street, Westminster, S.W.

1890. Robinson, Sydney Jessop, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1891. Roche, Francis James, Shanghai Water Works, Shanghai, China.

1890. Rochford, John, Commissioners of Irish Lights, Westmoreland Street, Dublin.

1888. Rock, John William, Exchange Corner, Pitt Street, Sydney, New South Wales: (or care of E. G. Rock, The Red House, Ingatestone.)

1879. Rodger, William, care of Messrs. C. H. B. Forbes and Co., 3 Elphinstone Circle, Bombay: (or care of Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.)

1892. Rodgers, John, Messrs. J. S. Rodgers and Sons, Newcastle, New South Wales.

1884. Rodrigues, José Maria de Chermont, Rua de S. Pedro 54 sobrado, Rio de Janeiro, Brazil.

1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.

1885. Rogers, Henry John, Watford Iron Works, Watford. [*Engineer, Watford.*]

1887. Rogers, Horace Wyon, 43 Upper Thames Street, London, E.C.

1892. Ronald, Henry, Small Arms Ammunition Factory, Dum Dum, near Calcutta, India: (or care of James Ronald, 10 Campbell Terrace, Plumstead.)

1889. Rosenthal, James Hermann, Babcock and Wilcox Boiler Co., 114 Newgate Street, London, E.C.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1893. Rounthwaite, Henry Morrison, 15 Nicosia Road, Wandsworth Common, London, S.W.

1856. Rouse, Frederick, Locomotive Department, Great Northern Railway, Peterborough.

1878. Routh, William Pole, Sutton Court, Sutton, Surrey.

1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.

1892. Rowe, Almond, Senior Government Marine Surveyor, Singapore, Straits Settlements.

1891. Rowland, Bartholomew Richmond, Messrs. Luke and Spencer, Ardwick, Manchester.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, General Manager, Bute Shipbuilding Engineering and Dry Dock Co., Bute Dry Dock, Roath Basin, Cardiff. [*Caisson, Cardiff.*]

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1864. Saïd, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 9 Park Crescent, Portland Place, London, W.)

1892. Sainsbury, Francis Charles Barrett, 15 Queen Square, Bristol.

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and 23 St. Ermin's Mansions, Westminster, S.W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1890. Sandberg, Christer Peter, 19 Great George Street, Westminster, S.W.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.

1871. Sanders, Richard David, Hartfield House, Eastbourne.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1891. Sands, Harold, 41 Widmore Road, Bromley, Kent.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]

1891. Savill, Arthur Slater, Exhaust Steam Injector Company, 4 St. Ann's Square, Manchester.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.* 7068.]; and North Court, Hassocks, R.S.O., Sussex.

1893. Saxon, Alfred, Engineering Works, Openshaw, Manchester.

1869. Scarlett, James, Messrs. E. Green and Son, 2 Exchange Street, Manchester; and Stamford Road, Bowdon, R.O., near Altrincham.

1890. Schofield, George Andrew, General Manager, Sicilian Railways, Palazzo Brijuccia, Palermo, Sicily: (or care of I. D. Schofield, Oakfield, Alderley Edge, Cheshire.)

1886. Scholes, William Henry, 1255 n/n Rivadavia, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W. [*Schönheyder, London.*]

1880. Schram, Richard, 17A Great George Street, Westminster, S.W. [*Schram, London.*]

1890. Schroller, William, 13 Old Elvet, Durham. [*Bulumatari, Durham.*]

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Lyncot, Romford.

1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India: Poona Villa, Beechgrove Terrace, Aberdeen: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1891. Scott, Arthur Forbes, 69 Swan Arcade, Bradford.

1882. Scott, Charles Herbert, Messrs. Summers and Scott, High Orchard Iron Works, Gloucester.

1890. Scott, Frederick McClure, 89 Victoria Street, Liverpool.

1891. Scott, F. Walter, Messrs. George Scott and Son, 44 and 46 Christian Street, London, E. [*Thirty-four, London.* 4390.]

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1881. Scott, George Innes, Three Indian King's Court, Quayside, Newcastle-on-Tyne.

1891. Scott, Henry John, Ellangowan, Headlands, Kettering.

1877. Scott, Irving M., Union Iron Works, San Francisco, California.

1881. Scott, James, General Manager, President Land and Exploration Co., Pretoria, Transvaal, South Africa: (or Douglasfield, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1891. Scott, Robert Julian, School of Engineering, Canterbury College, Christchurch, New Zealand.

1861. Scott, Walter Henry, Park Road, East Molesey, near Kingston-on-Thames.

1884. Scott-Moncrieff, William Dundas, 14 Victoria Street, Westminster, S.W.

1868. Scriven, Charles, Ledsham Dene, Newton Road, Leeds. [*Scriven, Leeds.*]

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1892. Seaman, Charles Joseph, Stockton Forge Works, Stockton-on-Tees. [*Forge, Stockton-on-Tees.*]

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1886. Seddon, Robert Barlow, Manager, Wigan Wagon Works, Wigan.

1891. Selby, Millin, 14 Rue de la Gare, Lille, France.

1882. Selfe, Norman, 279 George Street, Sydney, New South Wales.

1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1888. Sellers, George, 5 Augusta Street, Dairy House Road, Derby.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennyslvania, United States.

1891. Sellier, Alphonse Louis, 74 St. James Street, Sanfernando, Trinidad.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster; and 6 Victoria Street, Westminster, S.W.

1872. Shanks, Arthur, Fairmile, Cobham, Surrey.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1890. Shardlow, Ambrose, Ealing Works, Washford Road, Attercliffe, Sheffield.

1891. Sharp, Henry, 23 College Hill, London, E.C.; and Watersgreen, Brockenhurst, R.S.O., Hants.

1875. Sharp, Thomas Budworth, Consulting Engineer, Muntz Metal Works, Birmingham; and County Chambers A, Martineau Street, Birmingham. [*Budworth, Birmingham.*]

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Messrs. W. Shaw Kirtley and Co., Wellington Cast Steel Foundry, Middlesbrough.

1890. Sheldon, Harry Cecil, Messrs. W. P. Thompson and Boult, 63 Long Row, Nottingham.

1891. Shenton, James, Messrs. Tinker Shenton and Co., Hyde Boiler Works, Hyde, near Manchester.

1892. Shepherd, James, Messrs. Edward Ripley and Son, Bowling Dye Works, Bradford.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1875. Sheppard, Herbert Gurney, Chief Engineer, Assioot-Girgeh Railway, Assioot, Upper Egypt: (or 89 Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co Phœnix Foundry, 17 York Street, Liverpool.

1888. Shin, Tsuneta, Director, Ishikawajima Shipbuilding and Engineering Co., Tokyo, Japan.

1892. Shirlaw, Andrew, Suffolk Works, Oozells Street, Birmingham. [*Shirlaw, Birmingham.*]

1889. Shone, Isaac, 47 Victoria Street, Westminster, S.W.

1890. Shoosmith, Harry, Messrs. Priestman Brothers, Holderness Foundry, Hull.

1890. Shore, Alfred Thomas, Government Inspector of Steam Boilers, Custom House, Bombay, India.

1893. Shroff, Adurjee Burjorjee, Chiet Engineer, Sassoon Spinning Mills Bombay, India.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1891. Siemens, Alexander (*Life Member*), 12 Queen Anne's Gate, Westminster, S.W.

1888. Siemens, Frederick, 10 Queen Anne's Gate, Westminster, S.W.

1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Aquosity, London.*]

1885. Simpson, James Thomas, Executive Engineer, Henzada Division, Henzada, Burma.

1882. Simpson, John Harwood, Manchester Ship Canal, 65 King Street, Manchester.

1889. Sinclair, Nisbet, The William Cramp and Sons Ship and Engine Building Co., Philadelphia, Pennsylvania, United States.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1857. Sinclair, Robert Cooper, Chesham House, Cavendish Road, Balham, London, S.W.

1891. Sinclair, Russell, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales.

1881. Sisson, William, Quay Street Iron Works, Gloucester. [*Sisson, Gloucester.*]

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1892. Slight, George Henry, Sub-Director of Lighthouses, Valparaiso, Chile.

1885. Slight, William Hooper, Lidgerwood Manufacturing Co., Soerabaya, Java: (or care of G. H. Slight, 64 Cromwell Road, Fitzhugh, Southampton.)

1891. Sloan, Robert Alexander, Messrs. Sloan and Lloyd Barnes, Castle Chambers, 26 Castle Street, Liverpool. [*Technical, Liverpool.*]

1886. Small, James Miln, Messrs. Urquhart and Small, 17 Victoria Street, Westminster, S.W.

1889. Smelt, John Dann, Argentine Great Western Railway, 4 Finsbury Circus, London, E.C.

1879. Smith, Charles Hubert, Board of Trade Surveyors' Office, Leith.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1893. Smith, John, Salford Works, Richard Street, Birmingham.

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1891. Smith, John Reney, 16 Seaton Buildings, 17 Water Street, Liverpool.

1890. Smith, John Windle, Messrs. Thomas Drysdale and Co., 438 Calle Moreno, Buenos Aires, Argentine Republic: (or care of Edward Smith, The "Lock," Gainsborough.)

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness; and Rhine Hill, Stratford-on-Avon.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 18 Abingdon Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, Ordsal Station Electrical Works, Salford, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 124 Hagley Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds, [*Tomsmith, Leeds.*]

1890. Smith, Thomas Ridsdill, Earle's Shipbuilding and Engineering Works, Hull.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1890. Smith, William, London and Manchester Plate Glass Co., Sutton, St. Helen's, Lancashire.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, F.R.S., Ennerdale Hall, Frizington, near Carnforth.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1887. Sorabji, Shapurji, Bombay Foundry and Engine Works, Khetwady, Bombay: (or care of Messrs. S. and E. Ransome and Co., Billiter Buildings, 49 Leadenhall Street, London, E.C.)

1884. Soulsby, James Charlton, Windsor Slipways Dry Docks and Engineering Co., Grangetown, Cardiff.

1889. Souter-Robertson, David, Assistant Superintendent, Government Canal Foundry and Workshops, Roorkee, North Western Provinces, India.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1877. Soyres, Francis Johnstone de, 4 Arlington Villas, Clifton, near Bristol.

1893. Spence, Arthur William, Manager, Cork Street Foundry and Engineering Works, Dublin.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1892. Spencer, Henry Bath, British Steam Users' Insurance Society, Manchester; and 20 Central Road, Withington, Manchester.

1877. Spencer, John, Globe Tube Works, Wednesbury; and 14 Great St. Thomas Apostle, London, E.C. [*Tubes, Wednesbury. Tubes, London.*]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Ardwick, Manchester; and The Hill, Teignmouth.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1891. Spencer, William, Messrs. James Spencer and Co., Chamber Iron Works, Hollinwood, near Manchester.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India; and Whitehall Club, Parliament Street, Westminster, S.W.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W. [3117.]

1888. Stanley, Harry Frank, Messrs. Pontifex and Wood, Farringdon Works, Shoe Lane, London, E.C.; and 84 Finsbury Park Road, London, N.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.

1884. Stanton, Frederic Barry, 18 Bishopsgate Street Within, London, E.C. [*Barry Stanton, London.* 4084.]

1874. Stephens, Michael, Chief Locomotive Superintendent of the Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 17 Victoria Street, Westminster, S.W. [*Precursor, London.*]

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]

1888. Stephenson-Peach, William John, Askew Hill, Repton, Burton-on-Trent.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 28 Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1891. Stevens, James, 9 and 11 Fenchurch Avenue, London, E.C.

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.

1892. Stevinson, Thomas, Messrs. Hender and Stevinson, Nailsworth, near Stroud, Gloucestershire.

1893. Steward, George Richard, 15 Queen Street, Queen Victoria Street, London, E.C.

1877. Stewart, Alexander, Messrs. Thornton and Crebbin, Hammerton Street Iron Works, Bradford; and 3 Southbrook Terrace, Bradford.

1887. Stewart, Andrew, 41 Oswald Street, Glasgow.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]; and 8 Stamford Avenue, Preston Park, Brighton.

1888. Stiff, William Charles, Smethwick, Birmingham.

1892. Still, William Henry, Aden, Arabia.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1888. Stirling, Robert, Locomotive Department, North Eastern Railway, Gateshead.

1875. Stoker, Frederick William, Messrs. Easton, Anderson and Goolden, Erith Iron Works, Erith, S.O., Kent.

1877. Stokes, Alfred Allen, Elmcote, Godalming.

1892. Stone, Edward Herbert, Superintendent, Way and Works, East Coast Railway, Waltair, Madras, India.

1887. Stone, Frank Holmes, P.O. Box, Kingston, Jamaica.

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1888. Strachan, James, Stenton, near Prestonkirk.

1892. Strachan, John, 29 The Walk, Cardiff.

1888. Straker, Sidney, Messrs. Ewen and Straker, 37 Walbrook, London, E.C.; and 240 Stanstead Road, Forest Hill, London, S.E.

1891. Stringer, William, 20 Mount Street, Manchester.

1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil: (or 1 Albion Street, Hyde Park, London, W.)

1873. Strype, William George, 115 Grafton Street, Dublin. [*Strype, Dublin.*]

1889. Stuart-Hartland, Dare Arthur, 31 Dalhousie Square South, Calcutta, India.

1882. Sturgeon, John, 243 White Horse Road, Croydon.

1890. Stutzer, Waldemar, Koltchugin Brass and Copper Mill Co., Alexandrov Station, Jaroslav Railroad, Russia.

1882. Sugden, Thomas, Babcock and Wilcox Co., 147 Queen Victoria Street, London, E.C.

1890. Sulzer, Jacob, Messrs. Sulzer Brothers, Winterthur, Switzerland.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, 36 Bedford Street, Strand, London, W.C.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1887. Suverkrop, John Peter, Chief Engineer, East Tennessee Land Co., Harriman, Tennessee, United States: (or 1 Kew Gardens Road, Kew, Surrey.)

1882. Swaine, John, 9 Miles Road, Clifton, Bristol.

1884. Swan, Joseph Wilson, 57 Holborn Viaduct, London, E.C.; and Lauriston, Bromley, Kent.

1882. Swinburne, Mark William, Wallsend Brass Works, Newcastle-on-Tyne; and 117 Park Road, Newcastle-on-Tyne. [*Bronze, Wallsend.*]

1864. Swindell, James Swindell Evers, Homer Hill, Cradley, Staffordshire.

1890. Swinerd, Edward, Superintendent, Locomotive Carriage and Wagon Departments, Mogyana Railway, Campinas, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, Laurence Pountney Hill, London, E.C.)

1890. Swinnerton, Robert Allen William, Executive Engineer, Public Works Department, Bolarum, Dekkan, India.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and The Corner House, Shortlands, S.O., Kent.

1882. Tandy, John O'Brien, Locomotive Department, London and North Western Railway, Crewe; and 4 Wellington Villas, Wellington Square, Crewe.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1893. Tasker, Frederick, Messrs. Tasker Sons and Co., New Station Road, Sheffield. [*Tasker, Sheffield.* 1005.]

1876. Taunton, Richard Hobbs, 10 Coleshill Street, Birmingham.

1882. Tayler, Alexander James Wallis, 77 Victoria Road, Kilburn, London, N.W.

1874. Taylor, Arthur, Manager, Sociedad Anglo-Vasca, Villanueva del Duque, Provincia de Cordoba, Spain: (or 21 Victoria Road, Kensington, London, W.)

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, Paris; and 21 Victoria Road, Kensington, London, W.

1893. Taylor, Robert, Jun., Works Manager, Messrs. Asa Lees and Co., Soho Iron Works, Oldham.

1882. Taylor, Robert Henry, 2 Collingwood Street, Newcastle-on-Tyne; and 2 Winchester Terrace, Newcastle-on-Tyne.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, 17 Victoria Street, Westminster, S.W.

1891. Tetlow, Ernest, Messrs. Tetlow Brothers, Bottoms Iron Works, Hollinwood, near Manchester.

1877. Thom, William, Messrs. Yates and Thom, Canal Foundry, Blackburn.

1889. Thomas, James Donnithorne, 25A Old Broad Street, London, E.C. [*Kooringa, London.*]

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1888. Thomas, Philip Alexander, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Argument, London.*]

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1891. Thompson, James, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1875. Thompson, John, Highfield Boiler Works, Ettingshall, Wolverhampton. [*Boiler, Wolverhampton.*]

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons Southwick Shipbuilding Yard, Sunderland.

1880. Thompson, Thomas William, Eastham Ferry Pier, near Birkenhead.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1889. Thomson, Robert McNider, Kobe Engine Works, Kobe, Japan: (or care of William Hipwell, Hillside House, Sharnbrook, Bedford.)

1893. Thornbery, William Henry, Jun., 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, care of The Hydraulic Engineering Co., Chester.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1888. Thornton, Robert Samuel, West's Patent Press Co., Etawah, North Western Provinces, India.

1876. Thornycroft, John Isaac, F.R.S., Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Engineer, New South Wales Government Railways, Eveleigh Workshops, Sydney, New South Wales: (or care of Joseph Meilbek, 13 Victoria Street, Westminster, S.W.)

1884. Thwaites, Arthur Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford. [*Thwaites, Bradford.* 325.]

1887. Thwaites, Edward Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford. [*Thwaites, Bradford.* 325.]

1891. Tilley, Albert, care of Bernard Dawson, York House, Malvern Link, Malvern.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium. [*Société Meuse, Liége.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 38 South Street, Greenwich, London, S.E.

1890. Titley, Arthur, Messrs. Vaughton and Titley, 26 Great Charles Street, Birmingham.

1888. Todd, Robert Ernest, Mechanical Engineer, Tucuman, Estacion Provincia, Argentine Republic: (or care of William H. Todd, County Buildings, Land of Green Ginger, Hull.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and 28 Victoria Street, Westminster, S.W.

1857. Tomlinson, Joseph, 64 Priory Road, West Hampstead, London, N.W.

1888. Topple, Charles James, Machinery Department, Royal Arsenal, Woolwich.

1883. Tower, Beauchamp, 5 Queen Anne's Gate, Westminster, S.W.

1889. Towler, Alfred, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1886. Towne, Henry Robinson, Yale and Towne Manufacturing Co., Stamford, Connecticut, United States.

1893. Townsend, C. Collingwood, Captain R.A., Superintendent, Gun-Carriage Factory, Madras, India.

1890. Trail, John, Marine Superintendent, Knott's Prince Line of Steamers, Newcastle-on-Tyne.

1888. Travis, Henry, Assistant Superintending Engineer and Constructor of Shipping to the War Department, Royal Arsenal, Woolwich.

1889. Treharne, Gwilym Alexander, Pontypridd; and Aberdare.

1889. Trenery, William Penrose, 73 Via Milano, Genoa, Italy.

1883. Trentham, William Henry, 39 Victoria Street, Westminster, S.W.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1886. Trew, James Bradford, High Street, Watford, Herts.

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1885. Trueman, Thomas Brynalyn, Ferro Carril Buenos Aires al Pacifico, Junin, Argentine Republic: (or care of Thomas R. Trueman, 3 The Barons, Twickenham.)

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Bishopbriggs, Glasgow. [*Valve, Glasgow.* 1270.]

1885. Turnbull, John, Jun., 18 Blythswood Square, Glasgow. [*Turbine, Glasgow.* 59.]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1886. Turner, George Reynolds, Vulcan Iron Works, Langley Mill, near Nottingham; and 81 Highgate Road, London, N.W.

1887. Turner, Joshua Alfred Alexander, Inspector, Commissariat Mills and Bakeries, Bombay Presidency, Poona, India.

1882. Turner, Thomas, Shelton Iron and Steel Works, Stoke-on-Trent.

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1891. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W. [*Tweddell, Westminster, London.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 2 Newgate Street, London, E.C.

1889. Tyrrell, Joseph John, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1878. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

1875. Urquhart, Thomas, Commerce House, Invergordon, R.S.O., Ross-shire.

1880. Valon, William Andrew McIntosh, 140 and 141 Temple Chambers, Temple Avenue, London, E.C.; and Ramsgate. [*Valon, Ramsgate.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester [*Vaunting, Manchester.* 5106.]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]

1889. Vesian, John Stuart Ellis de, 5 Crown Court, Cheapside, London, E.C. [*Biceps, London.*]

1891. Vicars, John, Messrs. T. and T. Vicars, Furnace Foundry, Earlestown, Newton-le-Willows, Lancashire.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1888. Voysey, Henry Wesley, 1 Fordwych Road, Brondesbury, London, N.W.

1883. Waddell, James, 9 Ashton Terrace, Dowanhill, Glasgow.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, The Hon. Nowrosjee Nesserwanjee, C.I.E., Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Tardeo, Bombay.*]

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1875. Wailes, John William, South Shore, Gateshead-on-Tyne.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1888. Waister, William Henry, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1892. Waldron, Patrick Lawrence, Chief Engineer, Mail Steamer "Yomah," Irrawaddy Flotilla Co., Rangoon, Burma, India: (or 20 St. Joseph's Road, Aughrim Street, Dublin.)

1890. Walkeden, George Henry, Temperance Life Buildings, Swanston Street, Melbourne, Victoria.

1891. Walker, Arthur Tannett, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1890. Walker, Henry, 11 Oxford Terrace, Gateshead.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 3 Alexandra Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Matthew, 16 London Street, Fenchurch Street, London, E.C.

1884. Walker, Sydney Ferris, Cardiff Electrical Works, Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Hunter's Forge, New Bridge Street, Newcastle-on-Tyne. [*Dynamo, Newcastle-on-Tyne.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E. [*Bromo, London.*]

1890. Walker, William George, Battersea Polytechnic Institute, Battersea, London, S.W.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1881. Walkinshaw, Frank, Hartley Grange, Winchfield.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1893. Wallwork, Roughsedge, Union Bridge Iron Works, Charter Street, Manchester.

1891. Walmsley, John, Queen's Mills, Huddersfield.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, 24 Church Lane, Smethwick, near Birmingham.

1876. Ward, William Meese, Newton Villa, Claremont Road, Handsworth, R.O., near Birmingham.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, R.O., near Birmingham. [*Bolts, Birmingham.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.

1885. Warren, Henry John, Jun., Cornwall Boiler Works, Camborne.

1885. Warren, William, 5 Victoria Buildings, Hong Kong, China; 344 Dashwood House, Old Broad Street, London, E.C.: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.) [*Wakeful, London; or Hong Kong.*]

1882. Warsop, Henry, Clarendon Hotel, Nottingham.

1889. Warsop, Thomas, Coniston Copper Mines, Coniston, S.O., Lancashire.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1891. Waterous, Julius E., Waterous Engine Works Co., Brantford, Ontario, Canada.

1881. Watkins, Alfred, 121 Fenchurch Street, London, E.C.

1862. Watkins, Richard, 71 Blenheim Crescent, London, W.

1890. Watkinson, William Henry, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1890. Watson, George Coghlan, Manganese Bronze and Brass Co., St. George's Wharf, Deptford, London, S.E.; and 1 Farquharson Road, Croydon.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1879. Watson, Sir William Renny, Messrs. Mirrlees Tait and Watson, Glasgow.

1891. Watt, Charles, Melbourne Cable Tramway, 418 Little Collins Street, Melbourne, Victoria.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1884. Webb, Richard George, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India: (or care of Messrs. Richardson and Hewitt, 101 Leadenhall Street, London, E.C.)

1890. Webster, John James, 39 Victoria Street, Westminster, S.W.

1887. Webster, William, 6 Oxley Road, Singapore, Straits Settlements.

1883. Weck, Friedrich, Lilleshall Old Hall, near Newport, Shropshire.

1891. Weightman, Walter James, Engineer-in-Chief, Nilgiri Railway, Coonoor, Madras, India.

1888. Wellman, Samuel T., Wellman Iron and Steel Works, Thurlow, Pennsylvania, United States.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokyo, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 14 Castle Street, Liverpool. [*Referee, Liverpool.*]

1891. West, Leonard, Ravenhead Plate Glass Works, St. Helen's, Lancashire.

1874. West, Nicholas James, Messrs. Harvey and Co., 186 Gresham House, Old Broad Street, London, E.C.; and The Turret, West Heath Road, Hampstead, London, N.W.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* 3199.]

1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Bangkok, Siam: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York; and P.O. Box 230, Ridgewood, New Jersey, United States.

1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1888. Weyman, James Edwardes, Messrs. Weyman and Hitchcock, Church Acre Iron Works, Guildford.

1884. Whieldon, John Henry, 75 Ivydale Road, Nunhead, London, S.E.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, 11 Queen Victoria Street, London, E.C.

1874. White, Henry Watkins, Wynberg, Nightingale Square, Balham, London, S.W.

1888. White, William Henry, C.B., LL.D., F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

1890. Whitehouse, Edwin Edward Joseph, Monkbridge Iron Works, Leeds.

1876. Whiteley, William, Holly Mount, Edgerton, Huddersfield.

1891. Whittaker, John, Messrs. William Whittaker and Sons, Sun Iron Works, Oldham.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1878. Whytehead, Hugh Edward, North Staffordshire Tramways, Stoke-on-Trent.

1878. Wicks, Henry, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of John Spencer, 125 West Regent Street, Glasgow.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1891. Widdowson, John Henry, Britannia Works, Ordsal Lane, Salford, Manchester.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1889. Wigham, John Richardson, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1881. Wigzell, Eustace Ernest, Billiter House, Billiter Street, London, E.C. [*Wigzell, London.* 1844.]

1890. Wild, John, Falcon Iron Works, Oldham. [*Falcon, Oldham.*]

1886. Wildridge, John, Messrs. J. Wildridge and Sinclair, 97 Pitt Street, Sydney, New South Wales.

1890. Wildy, William Lawrence, Messrs. Richard Hornsby and Sons, 84 Lombard Street, London, E.C.

1892. Wilkinson, Edward R., 63 Middle Lane, Hornsey, London, N.

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1893. Williams, Arthur Edward, Resident Engineer, Dagenham Dock, Essex.

1883. Williams, Edward Leader, Engineer, Manchester Ship Canal Co., 41 Spring Gardens, Manchester. [*Leader, Manchester.* 688.]

1884. Williams, John Begby, Central Marine Engine Works, West Hartlepool.

1885. Williams, Nicholas Thomas, New Morgan Gold Mining Co., Dolgelly.

1847. Williams, Richard, Brunswick House, Wednesbury.

1890. Williams, Thomas David, Egremont, Battle Road, Ore, near Hastings.

1881. Williams, William Freke Maxwell, 29 Great St. Helen's, London, E.C. [*Wabash, London.*]

1873. Williams, William Lawrence, 16 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1889. Williams, William Walton, Jun., 25 Oakley Street, Chelsea, London, S.W.

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington; and South Lodge, Cockermouth.

1870. Willman, Charles, 26 Albert Road, Middlesbrough.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt: Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, St. Werburgh's, Eversley Road, Bexhill-on-Sea.

1892. Wilson, John Charles Grant, Locomotive Superintendent, Manila Railway, Manila, Philippine Islands.

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1890. Wilson, Joseph William, Jun., Vice-Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.

1880. Wilson, Robert, 10 St. Bride Street, London, E.C.; and 7 St. Andrew's Place, Regent's Park, London, N.W.

1883. Wilson, Robert, 13 Victoria Street, Westminster, S.W.

1890. Wilson, Robert James, 17 Kelvinhaugh Street, Glasgow.

1891. Wilson, Thomas, Morro Foundry, Iquique, Chile.

1873. Wilson, Thomas Sipling, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1891. Wimshurst, James Edgar, Messrs. William Esplen, Son, and Swainston, Billiter Buildings, 22 Billiter Street, London, E.C.

1890. Winder, Charles Aston, Messrs. Winder Brothers, Royds Works, Attercliffe, Sheffield.

1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.

1890. Wingfield, Digby Charles, Messrs. E. Beanes and Co., Falcon Works, Hackney Wick, London, N.E.

1887. Winmill, George, Locomotive and Carriage Superintendent, Oudh and Rohilkund Railway, Lucknow, India: (or Hare Street, Romford.)

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 2766.]

1884. Withy, Henry, Messrs. Furness Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]

1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Shanghai, China: (or 17 Dudley Street, Moss Side, Manchester.)

1888. Wolff, Gustav William, M.P., Messrs. Harland and Wolff, Belfast.

1881. Wood, Edward Malcolm, 3 Victoria Street, Westminster, S.W.

1887. Wood, Henry, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1885. Wood, Robert Henry, 15 Bainbrigge Road, Headingley, Leeds.

1884. Wood, Sidney Prescott, Semaphore Iron Works, Newport, Melbourne, Victoria: (or care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.)

1890. Wood, Thomas Royle, Assistant Locomotive Superintendent, Sola Works, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1890. Wood, William, 4 Wolfington Road, West Norwood, London, S.E.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, Southwark Bridge Road, London, S.E.

1893. Wormald, Henry, Resident Engineer, Ackton Hall Colliery, Featherstone, near Pontefract.

1874. Worsdell, Thomas William, Stonycroft, Arnside, near Carnforth.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)

1888. Worthington, Edgar, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and New Home, Wellington Road, Fallowfield, Manchester.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and Mill Bank, Vicarage Lane, Bowdon, R.O., near Altrincham.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester. [*Wrens, Manchester.*]

1881. Wrench, John Mervyn, Chief Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and Arundel House, Lower Road, Richmond, Surrey.

1860. Wright, Joseph, 16 Great George Street, Westminster, S.W.; and Lawnswood, Alexandra Road, Upper Norwood, London, S.E.
1878. Wright, William Barton, Cambridge House, Dover.
1871. Wrightson, Thomas, M.P., Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.
1891. Wroe, Joseph, 26 Park Avenue, Manchester, S.E.
1891. Wylde, Thomas, P. O. Box 455, Johannesburg, Transvaal, South Africa.
1886. Wylie, James, 83 Malvern Street, Stapenhill, Burton-on-Trent.
1865. Wyllie, Andrew, 1 Leicester Street, Southport.
1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.

1889. Yarrow, Alfred Fernandez, Isle of Dogs, Poplar, London, E.
1878. Yates, Henry, Brantford, Ontario, Canada.
1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)
1881. Yates, Louis Edmund Hasselts, District Locomotive and Carriage Superintendent, Eastern Bengal State Railway, Saidpore, Bengal, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)
1880. York, Francis Colin, Locomotive Superintendent, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of W. Hannay, 18 Portland Street, Leamington.)
1889. Young, David, 11 and 12 Southampton Buildings, London, W.C.
1879. Young, George Scholey, Engineer, Thames Iron Works, Orchard Yard, Blackwall, London, E.
1874. Young, James, Managing Engineer, Lambton Engine and Iron Works, Fence Houses.
1879. Young, James, Salroyd, 21 Cambalt Road, Putney, London, S.W.
1892. Young, Robert, Superintending Engineer, Penang Steam Tramways, Penang, Straits Settlements.
1887. Young, William Andrew, Messrs. Lobnitz and Co., Renfrew, near Paisley. [*Lobnitz, Renfrew.* 57, *Paisley.*]
1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

ASSOCIATE MEMBERS.

1888. Barker, Eric Gordon, Locomotive Superintendent, Wirral Railway, Dock Station, Birkenhead; and Guyse House, Oxton, R.O., near Birkenhead.

1893. Barker, Frederic William, Ferndale Road, Sefton Park, Liverpool.

1893. Beazley, Ernest, Messrs. Blandy Brothers and Co., Funchal, Madeira.

1893. Bishop, Henry, 38 Gresham Street, Lincoln.

1892. Bromly, Alfred Hammond, Castell Carn Dochan Gold Mine, Llanuwchllyn, near Bala, Merionethshire; and 359 Amhurst Road, Stoke Newington, London, N.

1893. Burden, Alfred George, care of Messrs. Tangye and Co., P. O. Box 818, Johannesburg, Transvaal, South Africa: (or care of George N. Burden, Oakfield, Teignmouth.)

1893. Corkhill, William, General Superintendent, Asiatic Steam Navigation Co., 6 Lyons, Calcutta, India.

1893. Cowell, John Ray, Messrs. Phillips and Cowell, 32 Queen's Terrace, Southampton. [*Philology, Southampton.*]

1887. Crosland, DelevanteWilliam, 22 Royal Crescent, Kensington, London, W.

1890. Day, Arthur Godfrey, Director of Studies, Science Art and Technical Schools, Bath.

1893. Edmondson, Alfred Richard, Central Board School, Deansgate, Manchester.

1893. Gritton, Joseph, 97 Highbury Quadrant, London, N.

1893. Human, Edwin, Superintendent, Technical School, Colombo, Ceylon; and Halifax House, Robinson Street, Cinnamon Gardens, Colombo, Ceylon.

1893. Jenkin, Charles James, Trewirgie, Redruth.

1893. Kershaw, Thomas, Technical School, Huddersfield.

1893. Kirk, Percy Roebuck, 2 Forest View, Epping New Road, Buckhurst Hill, S.O., Essex.

1893. Lea, Arthur Henry, Messrs. Lea Sons and Co., Pengwerne Works, Shrewsbury.

1893. Manton, Arthur Woodroffe, New Docks 14 and 15, H. M. Dockyard, Portsmouth.

1893. Mitchell, James Frederick Bruce, Messrs. George Gahagan and Co., Bellasis Road, Byculla, Bombay, India.

1893. Mountain, Benjamin, 82 Ravenswood Terrace, Hyde Park, Leeds.

1893. Moylan, William Morgan, care of Messrs. Grindlay and Co., Calcutta, India.

1893. Paterson, Robert Mair, Manager, Thames Cycle Co., Barnes, London, S.W.

1893. Pertwee, Herbert Arthur, Messrs. Elliott's Metal Co., Pembrey Copper Works, Burry Port, R.S.O., Carmarthenshire.

1893. Richey, William Frederick Albert, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.

1893. Roberts, Charles Thomas, 19 and 23 Chorlton Chambers, Johannesburg, Transvaal, South Africa. [*Roberts, Engineer, Johannesburg.*]

1893. Schloesser, Robert, P. O. Box 209, Johannesburg, Transvaal, South Africa: (or care of Adolf Schloesser, 185 Sutherland Avenue, London, W.)

1893. Segundo, Edward Carstensen de, 28 Victoria Street, Westminster, S.W.

1893. Stockton, Joseph Sadler, Stopper, Box, and Stamp Works, Icknield Street, Birmingham.

1893. Takatsuji, Narazo, Superintending Engineer, Calico Weaving Mill, Osaka, Japan.

1893. Talbot, Frederick William, Assistant Engineer, Lambeth Water Works, Surbiton, Surrey; and 7 Prospect Place, Long Ditton, Surbiton, Surrey.

1893. Tenney, Dennis, The White Cottage, Attenborough, Nottingham.

1893. Thomasson, Lucas, Cotlands, London Colney, St. Albans.

1893. Thomson, James Watson, Robert Gordon's College, Aberdeen.

1893. Tomes, William Jameson, Locomotive Department, London and South Western Railway, Nine Elms, London, S.W.

1893. Tomlinson, William Augustus, P.O. Box 575, Johannesburg, Transvaal, South Africa: (or care of John Tomlinson, Birthorpe Manor, Billingborough, near Folkingham.)

1893. Turner, Henry Arthur, care of Arthur Koppel, 33 Billiter Buildings, London, E.C.

1893. Walker, Charles Christopher, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield. [*Founder, Sheffield.* 376.]

1893. Watson, George, The Glenfield Engineering Works, Kilmarnock.

1893. Wells, Sidney Herbert, Principal, Battersea Polytechnic Institute, Battersea, London, S.W.

1893. Wilkins, George Cornelius, Sir W. G. Armstrong Mitchell and Co., Elswick Ordnance Works, Newcastle-on-Tyne.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Cross George Street, Sheffield.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland; and The Glen, Newry, Ireland.

1889. Barr, John, Glenfield Engineering Works, East Shaw Street, Kilmarnock.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield; and 38 Wellington Street, Higher Broughton, Manchester.

1890. Birch, John Grant, 10 and 11 Queen Street Place, London, E.C.

1892. Bowman, Frederic Hungerford, D.Sc., F.R.S.E., Ash Leigh, Ashley Heath, Bowdon, R.O., near Altrincham.

1888. Brown, Harold, 2 Bond Court, Walbrook, London, E.C.

1890. Burt, John Mowlem, Messrs. John Mowlem and Co., 19 Grosvenor Road, Pimlico, London, S.W.

1892. Carpenter, Henry James, 15 Church Road, De Beauvoir Town, London, N.

1891. Carter, Frederick Heathcote, 9 Oxford Street, Manchester. [*Girder, Manchester.*]

1889. Castle, Frederick George, The People's Palace Technical Schools, Mile End Road, London, E.

1889. Chamberlain, John George, Messrs. Joseph Wright and Co., Neptune Forge, Tipton.

1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1890. Chubb, Richard, Messrs. Gillison and Chadwick, 10 Tower Buildings, Liverpool.

1893. Clarke, Edward Fuhrmann, Curzon Chambers, Paradise Street, Birmingham; and Four Oaks, Sutton Coldfield, near Birmingham,

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]

1892. Cooper, Thomas Lancelot Reed, 79 Western Road, Hove, near Brighton.

1891. Cornett, James Porteus, Ford Paper Works, near Sunderland. [*Ford, Hylton. Nor. Dis.* 135.]

1892. Cryer, Arthur, University College, Cardiff.

1893. Darlington, John, Engine and Boiler Insurance Co., Manchester; and 3 Marlborough Gardens, Ealing, London, W.

1892. Davis, George Brown, Palace Wharf, Stangate, London, S.E.; and Cambridge House, 242 South Lambeth Road, London, S.W.

1892. Fauvel, Charles James, 15 George Street, Mansion House, London, E.C.

1891. Foster, George, Hecla Foundry Steel Works, Sheffield; and Lyme Villa, Rotherham.

1889. Golby, Frederick William, 36 Chancery Lane, London, W.C.

1889. Götz, Carl Johann Wilhelm, Messrs. John M. Sumner and Co., 2 Brazennose Street, Manchester.

1889. Gregory, George Francis, Boarzell, Hawkhurst.

1887. Hind, Enoch, Edgar Rise, Nottingham.

1891. Jackman, Joseph, Persberg Steel Works, Pothouse Road, Attercliffe, Sheffield. [*Persberg, Sheffield.* 94.]

1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]

1882. Jackson, William, Kingston Cotton Mill, Hull. [*Cotton, Hull.*]

1891. Jennings, George Henry, Stangate, Lambeth, London, S.E. [*Jennings, London.* 4680.]

1890. Jennings, Sidney, Stangate, Lambeth, London, S.E. [*Jennings, London.* 4680.]

1865. Longsdon, Alfred, 9 New Broad Street, London, E.C.

1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.* 131.]

1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]

1890. McGillivray, William, Messrs. Austin McGillivray and Co., Falcon Works, Sheffield. [*Austin, Sheffield.*]

1889. McKinnel, William, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1891. McMeekin, Adam, Cogry Flax Spinning Mills, Doagh R.S.O., Co. Antrim, Ireland.

1890. Meggitt, Samuel Newton, Messrs. Ibbotson Brothers and Co., Globe Steel Works, Sheffield.

1889. Miles, William Henry, 23 Barnato Buildings, and P.O Box 1860, Johannesburg, Transvaal, South Africa.

1891. Monie, Hugh, Jun., Textile Section, Victoria Jubilee Technical Institute, Byculla, Bombay, India: (or care of Hugh Monie, Springfield, Belfast.)

1892. Morley, John, Sanitary Engineering Works, Palace Wharf, Stangate, London, S.E.

1889. Nasmith, Joseph, 4 Arcade Chambers, St. Mary's Gate, Manchester.

1887. Neville, Edward Hermann, Fabrica del Piles, Gijon, Spain.

1886. Newton, Henry Edward, 6 Bream's Buildings, Chancery Lane, London, E.C.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]
1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.
1888. Peake, Robert Cecil, Cumberland House, Redbourn, near St. Albans.
1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield.
1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield.
1890. Perry, Edwin, Queen Street, Newcastle-on-Tyne.
1884. Phillips, Richard Morgan, 21 to 24 State Street, New York, United States. [*Sarita, New York.*]
1891. Pirrie, John Barbour, Barn Flax Spinning Mills, Carrickfergus, Co. Antrim, Ireland.
1891. Plant, George, Moseley Road School, Birmingham.
1891. Rankin, Thomas Thomson, Principal, Coatbridge Technical School and West of Scotland Mining College, Coatbridge.
1886. Raven, Henry Baldwin, Messrs. Hare and Co., Temple Chambers, Temple Avenue, London, E.C.
1892. Reed, Ernest Charles, 35 Queen Victoria Street, London, E.C.
1891. Rochfort, Bertram, Rua da Guitanda 55, Rio de Janeiro, Brazil.
1891. Rowcliffe, William Charles, 1 Bedford Row, London, W.C.
1888. Rowell, John Henry, New Brewery, High Street, Gateshead.
1890. Schofield, John William, Messrs. Gregory and Bramall, Soho Steel and File Works, Sheffield.
1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]
1893. Simpson, Edward Percy, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.
1891. Spencer, Francis Henry, P.O. Box 1338, Johannesburg, Transvaal, South Africa.
1878. Stalbridge, The Right Hon. Lord, 12 Upper Brook Street, Grosvenor Square, London, W.
1892. Stead, John Edward, 5 Zetland Road, Middlesbrough.
1886. Stumore, Frederick, 34 Leadenhall Street, London, E.C.
1890. Taylor, John, 99 and 101 Fonthill Road, Finsbury Park, London, N.; and Stockport.
1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.
1893. Wadham, Arthur, 171 Queen Victoria Street, E.C. [*Wadham, London.*]
1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1892. Whitehead, Richard David, Municipal Technical College, Green Hill, Derby.

1892. Widdows, Francis R., Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

1891. Wiseman, Edmund, Cheapside and John Street, Luton. [*Wiseman, Luton.*]

GRADUATES.

1892. Adams, Sidney Rickman, Dunraven, 114 Palace Road, Tulse Hill Park, London, S.W.

1885. Addis, Frederick Henry, District Locomotive Superintendent, Rajputana Malwa Railway, Mhow, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1893. Alderson, Charles Albert Heselton, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 13 Cheviot Street, Lincoln.

1890. Alderson, George Alexander, Norland House, Ramleh, Alexandria, Egypt.

1874. Allen, Francis, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria, Egypt: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1882. Anderson, William, Locomotive Department, North Eastern Railway, Gateshead,

1878. Appleby, Charles, Jun., 89 Cannon Street, London, E.C.

1889. Ashford, John, Municipal Technical School, Midland Institute, Paradise Street, Birmingham.

1890. Aubin, Percy Adrian, 29 St. James' Street, St. Helier's, Jersey.

1888. Bailey, Wilfred Daniel, India-rubber Gutta-percha and Telegraph Works, Casilla de Correo 1212, Buenos Aires, Argentine Republic.

1889. Barrow, Arthur Robert Maclean, Locomotive Department, North Western Railway, Sukkur, India: (or care of A. M. Barrow, 13 Upper Maze Hill, St. Leonard's-on-Sea.)

1882. Barstow, Thomas Hulme, Manager, Kaihu Railway, Dargaville, Auckland, New Zealand.

1893. Bealey, Harold Edward, Messrs. Bolckow Vaughan and Co., Cleveland Iron and Steel Works, South Bank, R.S.O., Yorkshire; and The Vicarage, Middlesbrough.

1893. Bedbrook, James Albert Harvey, Haresfield, Blenkarne Road, Wandsworth Common, London, S.W.

1888. Bell, Alexander Dirom, The Woll, Hawick.

1884. Bell, Robert Arthur, East Indian Railway, Cuddalore (New Town), Madras, India: (or care of Mrs. Bell, 30 Brompton Crescent, London, S.W.)

1890. Bell, William Thomas, Sunny Mount, Yarborough Road, Lincoln.

1880. Birkett, Herbert, Calle Lima 1159, Buenos Aires, Argentine Republic; and care of Messrs. Horne and Birkett, 4 Lincoln's Inn Fields, London, W.C.

1884. Bocquet, Harry, Locomotive Carriage and Wagon Superintendent, North West Argentine Railway, Tucuman, Argentine Republic: (or care of Mrs. Bocquet, Llanwye, Hampton Park, Hereford.)

1888. Bradley, Arthur Ashworth, Robinson Gold Mining Co., P.O. Box 787, Johannesburg, Transvaal, South Africa: (or care of Rev. Gilbert Bradley, St. Edmund's Vicarage, Dudley, Worcestershire.)

1887. Bremner, Bruce Laing, 21 Langworthy Road, Manchester: (or Streatham House, Canaan Lane, Edinburgh.)

1878. Brooke, Arthur, Post Office, Otahuhu, Auckland, New Zealand: (or care of Miss Helen Brooke, Sunnymead, The Rise, Sidcup, S.O., Kent.)

1890. Brousson, Robert Percy, City and Guilds of London Central Institution, Exhibition Road, London, S.W.

1889. Brown, Arthur Selwyn, Hayes Street, Neutral Bay, Sydney. New South Wales.

1893. Bruce, Robert Arthur, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1880. Buckle, William Harry Ray, 11 Billiter Buildings, 49 Leadenhall Street, London, E.C.

1886. Budenberg, Christian Frederick, Messrs. Schäffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester; and Bowden Lane, Marple, Stockport. [*Manometer, Manchester.* 899.]

1892. Bulwer, Ernest Henry Earle, Messrs. George Fletcher and Co., Poplar Iron Works, King Street, Poplar, London, E.

1890. Burne, Edward Lancaster, Messrs. Weyman and Hitchcock, Church Acre Iron Works, Guildford.

1893. Burtt, George Frank, Locomotive Department, London Brighton and South Coast Railway, Brighton; and 27 Rosehill Terrace, Brighton.

1891. Butcher, Walter Edward, Locomotive Department, London Brighton and South Coast Railway, Brighton; and Cumberland Villa, Carshalton Road, Sutton, Surrey.

1891. Buttenshaw, George Eskholme, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1889. Calastremé, John Carlos, Otis Elevator Co., Mansion House Buildings, 4 Queen Victoria Street, London, E.C.

1891. Caswell, Charles Henry, Naval Construction and Armaments Works, Barrow-in-Furness.

1889. Challen, Walter Bernard, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1890. Chatwood, Arthur Brunel, Chatwood's Safe and Lock Co., 76 Newgate Street, London, E.C.

1891. Church Harry, Ingeniero, para la Colonia San Gustavo, La Paz, Entre Rios, South America: (or care of George Church, Willington, Bedford.)

1890. Cleeves, John Frederick, Messrs. E. A. Cleeves and Co., 3 Mileage Wharf, Westbourne Park Road, London, W.

1892. Cleverly, William Bartholomew, Lambeth Water Works, Brixton, London, S.W.

1885. Clift, Leslie Everitt, 1 Holborn Place, High Holborn, London, W.C.

1892. Collingridge, Harvey, Messrs. Fawkner Rogers and Co., 11 and 12 New Bridge Street, London, E.C.; and The Elms, Hornsey, London, N.

1889. Cook, George Norcliffe, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1888. Cox, Herbert Henry, Hillside, Falmouth.

1891. Cutler, Samuel, Jun., Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.

1890. Davidson, Albert, Messrs. Hattersley and Davidson, Arundel Engineering Works, 14 and 16 Arundel Street, Sheffield.

1884. Dixon, John, Eastwood Villa, Lytham, near Preston, Lancashire.

1893. Douglas, William Saunders, Consett Iron Works, Consett, R.S.O., County Durham; and Parliament Street, Consett, R.S.O., County Durham.

1891. Douglass, Alfred Edwards, South Staffordshire Water Works, Paradise Street, Birmingham.

1891. Duncan, Martin Gordon, Lexden, 63 Elmfield Road, Upper Tooting, London, S.W.

1892. Edgcome, James Edmund, Resident Engineer, Electric Light Station, Kingston-on-Thames.

1891. Edwards, Herbert Francis, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1885. Edwards, Walter Cleeve, Assistant Engineer, Midland Railway, Greymouth, New Zealand.

1892. Fletcher, Joseph Ernst, Messrs. Thomas Firth and Sons, Norfolk Steel Works, Sheffield.

1893. Fox, Frederick Joseph, Messrs. George Wailes and Co., 258 Euston Road, London, N.W.

1890. Garrett, Frank, Jun., Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk.

1891. Gillatt, Thomas Stanley, care of A. C. Chamberlin, Kelburne Estate, Haputalia, Colombo, Ceylon: (or care of Mrs. Gillatt, Broomknowe, Row, Dumbartonshire.

1891. Gregory, Henry Hodges Mogg, Messrs. Sanders and Co., Rivington Works, Rivington Street, Great Eastern Street, London, E.C.

1890. Hatton, Thomas Reginald, Grosvenor House, Gloucester Road, Ross Herefordshire.

1889. Hayward, Robert Francis, Messrs. Crompton and Co., Arc Works, Chelmsford.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, Room 633, Chamber of Commerce, Portland, Oregon, United States.

1893. Heinrich, Herbert Rodolph, London Tilbury and Southend Railway Works, Plaistow, London, E.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1891. Hodgson, William James, Central Chemical Co., 182 London Road, Nottingham.

1887. Hogg, William, Craigmore, Blackrock, Dublin.

1884. Holt, Follett, Ferro Carril Buenos Aires y Rosario, La Banda, Argentine Republic: (or care of Robert Hallett Holt, Land Registry, Staple Inn, Holborn, London, W.C.)

1889. Hosgood, Thomas Watkin, Sketty, near Swansea.

1891. Hosgood, Walter James, Locomotive Department, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosken, Arthur Fayrer, Locomotive Department, Caledonian Railway, Polmadie, Glasgow.

1889. Howard, Geoffrey, Britannia Iron Works, Bedford.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1891. Hughes, Edward Sinclair Bremner, Madgefield, Helensburgh.

1890. Jones, Arthur Dansey, Locomotive Works, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1891. Jordan. Frederic William, 42 Wells Street, Mortimer Street, Cavendish Square, London, W.

1889. Joy, Basil Humbert, 17 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1883. Lander, Philip Vincent, Lyndhurst, Hampton Wick, R.O., Kingston-on-Thames: (or care of W. W. Lander, Imperial Ottoman Bank, 26 Throgmorton Street, London, E.C.)

1881. Lawson, James Ibbs, Resident Engineer, New Zealand Railways, Invercargill, Otago, New Zealand.

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and 89 Albany Road, Cardiff.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 267, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1893. Mackesy, Walter, Stanners Closes Steel Works, Wolsingham, near Darlington.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1892. Marks, Alfred Pally, 155 Adelaide Road, London, N.W.

1889. Marshall, Frank Theodore, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1888. Marten, Hubert Bindon, Contractor's Office, Midland Railway, Ampthill; and Pedmore, Stourbridge.

1886. Mattos, Alvaro Gomes de, 98 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1892. Miles, Frederick Hudson, Metropolitan Railway Works, Neasden, London, N.W.

1891. Mills, Matthew William, Moss Foundry, Heywood, near Manchester.

1867. Mitchell, John, Swaithe Hall, Barnsley.

1893. Monckton, Charles John, Messrs. T. H. Saunders and Co., Rye Paper Mill, High Wycombe.

1868. Moor, William, Ocean House, Hartlepool.

1893. Morgan, George Herbert, University College, Liverpool.

1892. Murray, David James, 54 Park Street, Greenheys, Manchester.

1878. Newall, John Walker, Suffolk House, Laurence Pountney Hill, London, E.C.

1883. O'Connor, John Frederick, 16 and 18 Exchange Place, New York, United States.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1892. Osmond, Frederick John, Whitworth Works, Rea Street South, Birmingham.

1881. Oswell, William St. John, Messrs. Oswell and Henry, Calle Defensa 117 al 119, Buenos Aires, Argentine Republic.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.

1887. Paterson, John Edward, Chief Mechanical Engineer's Office, New South Wales Government Railways, Wilson Street, Eveleigh, Sydney, New South Wales.

1892. Payton, Frank John, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1890. Philipson, John, Jun., Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1890. Powell, Frederick, York House, Malvern Link, Malvern.

1892. Power, Arthur Cyril, 2 Rheinstein Villas, Church Road, Teddington, S.O., Middlesex.

1893. Price, William Frederick, National Electric Supply Co., 119A Fishergate, Preston.

1887. Price-Williams, John Morgan, 28 Ormiston Road, Westcombe Park, Blackheath, London, S.E.

1892. Ransom, Herbert Byrom, Messrs. Manlove Alliott and Co., 57 Gracechurch Street, London, E.C.

1892. Redfern, Charles George, 122 Bethune Road, Stamford Hill, London, N.

1884. Reynolds, Thomas Blair, 28 Victoria Street, Westminster, S.W.

1892. Ridley, James Cartmell, Jun., 3 Summerhill Grove, Newcastle-on-Tyne.

1889. Roope, Walter, Stisted, Badulla, Ceylon: (or care of Mrs. Roope, Hangerfield, Witley, Godalming.)

1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.

1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.

1890. Sanders, Percy Henry, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.

1890. Saxelby, Herbert Raffaelle, Messrs. J. Copeland and Co., Poultney Street Engine Works, Dobbies Loan, Glasgow.

1892. Scarfe, George Norman, Fursby House, Finchley, London, N.

1881. Scott, Ernest, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]

1892. Seymour, William Frederick Earl, Laboratory, Great Western Railway, Swindon.

1893. Sharpley, George Ruston, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1892. Shepherd, James Horace, Great Western Railway, Swindon.

1886. Silcock, Charles Whitbread, Wood House, Ely.

1887. Simkins, Charles Wickens, Jun., Amguri Tea Estate, Amguri Post Office, Sibsagar, Assam, India: (or care of Charles W. Simkins, The Lodge, Lowdham, near Nottingham.)

1893. Simon, Ingo, 20 Mount Street, Manchester.

1891. Smith, Joseph Philip Grace, Polytechnic School of Engineering, 309 Regent Street, London, W.

1891. Snell, John Francis Cleverton, St. Pancras Electricity and Public Lighting Department, 47 Stanhope Street, London, N.W.

1892. Stokes, Frank Torrens, P.O. Box 1355, Johannesburg, Transvaal, South Africa.

1883. Swale, Gerald, The Cedars, Wiarton, Ontario, Canada.

1887. Tabor, Edward Henry, Fennes, Braintree.

1889. Tangye, Harold Lincoln, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1884. Taylor, Joseph, 24 Hawthorn Grove, Heaton Moor, near Stockport.

1884. Taylor, Maurice, 39 Rue de Lisbonne, Paris.

1891. Vaizey, John Leonard, Locomotive Works, Great Eastern Railway, Stratford, London, E.; and 6 Grove Crescent, Stratford, London, E.

1892. Vezey, Albert Edward, Electrical Department, London and North Western Railway Works, Crewe.

1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.

1888. Waddington, Samuel Sugden, 35 King William Street, London Bridge, London, E.C.

1885. Wakefield, William Marsden, Buckingham House, Government Place, Calcutta, India.

1884. Walker, Ralph Teasdale, Fabriek Sragie, Pekalongan, Java: (or Kaliemaas, Alleyne Park, West Dulwich, London, S.E.)

1892. Wallis, William Wallace, care of Herbert Wallis, Saxonhurst, Redpath Avenue, Montreal, Canada.

1888. Waring, Henry, Engineer, Dublin Laundry Co., Milltown, near Dublin.

1892. Warton, Richard George Frank, Wallsend Pontoon Works, Bute Docks, Cardiff.

1886. Wesley, Joseph A., Clarke's Crank and Forge Works, Lincoln.

1880. Weymouth, Francis Marten, 3 Goldsworth Villas, Heathfield Road, Wandsworth, London, S.W.

1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 44 Trumpington Street, Cambridge.)

1889. Wigham, John Cuthbert, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1892. Williams, Arthur Edward, Messrs. Bramwell and Harris, 5 Great George Street, Westminster, S.W.

1889. Willis, Edward Turnley, 99 Shooter's Hill Road, Blackheath, London, S.E.

1890. Wilson, Alexander Cowan, Osgathorpe Hills, Sheffield.

1889. Winkfield, Richard Ernest, Metropolitan Electric Supply Co., 17 South Street, Manchester Square, London, W.

1890. Winmill, Hallett, P.O. Box 386, Johannesburg, Transvaal, South Africa: (or 14 Hamfrith Road, Stratford, London, E.)

1893. Wort, Walter Edward, Messrs. H. A. House and Sons, Columbine Ship Yard, East Cowes, Isle of Wight.

1887. Wrench, John Henry Kirke, 119 West Huron Street, Chicago, United States: (or care of E. M. Wrench, Park Lodge, Baslow, Chesterfield.)

1889. Wright, Howard Theophilus, 16 Great George Street, Westminster, S.W.

1890. Wright, William Carthew, General Post Office, Melbourne, Victoria: (or care of Dr. Gaskoin Wright, 253 Eccles New Road, Salford, Manchester.)

1891. Yerbury, Frederick Augustus, 17 Victoria Street, Westminster, S.W.

Institution of Mechanical Engineers.

PROCEEDINGS.

August 1893.

The Summer Meeting of the Institution was held in Middlesbrough, commencing on Tuesday, 1st August 1893, at Ten o'clock a.m.; Dr. William Anderson, F.R.S., President, in the chair.

The President, Council, and Members were received in the Town Hall by the Mayor of Middlesbrough, Charles Lowthian Bell, Esq., and by the Chairman, Jeremiah Head, Esq., and Members of the Reception Committee.

The Mayor said it fell to his lot, as representing the Corporation of Middlesbrough, to welcome to the town one of the most important institutions, not only in England but in the world. That it was to him a great pleasure to do so, he need scarcely say; he felt it a great honour that he should be the person chosen by the burgesses of Middlesbrough to welcome in the capacity of Mayor the Institution of Mechanical Engineers. On behalf of himself and of the aldermen and burgesses of Middlesbrough, he could assure the members that it gave them the greatest pleasure to receive the Institution here on the occasion of the annual summer meeting. In giving this assurance he spoke not only for the Corporation, but also for the body of men who had been the making of Middlesbrough, namely the ironmasters and those who were interested in the industries of the Cleveland district. He trusted the members would find their visit a pleasant one, and that during the week of their meeting their excursions would be instructive as well as interesting. Although

(The Mayor.)
Middlesbrough might be regarded as one of England's youngest children, he thought it would be found that the inhabitants were using their brains to bring nature as much as possible to their service in the works they were carrying out. On behalf of the town of Middlesbrough he desired to offer the members of the Institution a most hearty welcome.

Mr. Jeremiah Head, Past-President, had the honour, as Chairman of the Reception Committee, to echo every word uttered by the Mayor in the way of welcome to the Institution of Mechanical Engineers. The Reception Committee comprised upwards of 170 names representing the leading men connected with the staple industries of the district. Through their executive they had occupied themselves for the last eight months, together with the Council of the Institution, in making arrangements for the present meeting. The result would be found in the programme. The Committee had only to say that they trusted the programme would be gone through without any hitch, and that the members of the Institution would find it conducive to their entertainment and instruction while they were in Middlesbrough. He hoped also that nature would second their efforts, and that the dry and sunny weather which had so long prevailed would continue a little longer, so as to make the meeting as pleasant as possible. And when the time came for the members to return to their several homes, he trusted they would carry away with them pleasant memories of Middlesbrough, and of those whose avocations compelled them to reside in this somewhat cold, rather smoky, but not altogether inhospitable region.

The President replied that, on behalf of the Council and Members of the Institution of Mechanical Engineers, he offered to his Worship the Mayor, and to the Chairman of the Reception Committee, his sincere thanks for the warm manner in which they had welcomed them. That the warmth was not merely of manner need scarcely be said; for those who had acted so assiduously as members of the Reception Committee had shown by the work they had done and by the arrangements they had made, of which the effects would be seen during the next two or three days, that they had put their heart into the business, and were really glad to see the members of the Institution among them. Middlesbrough was a historic place in the sense that, while it was one of the youngest of the great iron-producing districts, there were associated with it names known all over the world as those of pioneers in the application of exact science to the art of metallurgy. The Mayor himself bore a name which was honoured throughout the world; and the works with which he and his father Sir Lowthian Bell, and his brother Mr. Hugh Bell, were associated—the Clarence Iron Works—were known wherever metallurgy existed. The Ormesby Iron Works also, of which Mr. Charles Cochrane was the head, enjoyed an equal reputation. He would draw the attention of the members to the circumstance that there were at the present moment upon the platform four Past-Presidents of the Institution—Sir Lowthian Bell, Sir Frederick Bramwell, Mr. Cochrane, and Mr. Head—three of whom were intimately associated with the astonishing development of Middlesbrough, and had proved themselves second to none as Presidents of the Institution during their periods of office. On every side the members would see developed in Middlesbrough in the most perfect manner the application of science to the arts with which the Institution was specially connected; and they would find themselves associated here with the men who had converted a once insignificant place into a producing centre of the highest importance. On behalf of the Institution he thanked the Mayor for his kindness in attending the meeting, especially as he knew that he had done so at considerable personal sacrifice on account of his recent illness.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following forty candidates were found to be duly elected :—

MEMBERS.

Baldwin, Alfred, M.P.,	Stourport.
Beare, Thomas Hudson, F.R.S.E.,	London.
Berry, Henry,	Leeds.
Boyd, James Tennant,	Bombay.
Burnes, Thomas, R.N.,	Simon's Town.
Campbell, James Alexander Miller,	Liverpool.
Dall, John,	Belfast.
Eden, Francis Fleetwood,	Buenos Aires.
Milligan, William Scott,	Sowerby Bridge.
Oke, Francis Robert,	Crewe.
Raven, Vincent Litchfield,	Gateshead.
Ridley, James Taylor,	Cardiff.
Spence, Arthur William,	Dublin.
Taylor, Robert, Jun.,	Oldham.
Thornbery, William Henry, Jun.,	Birmingham.

ASSOCIATE MEMBERS.

Barker, Frederic William,	Liverpool.
Beazley, Ernest,	Madeira.
Cooper, William James,	Barnstaple.
Gritton, Joseph,	Woolwich.
Human, Edwin,	Colombo.
Jenkin, Charles James,	Redruth.
Kershaw, Thomas,	Huddersfield.
Kirk, Percy Roebuck,	London.
Manton, Arthur Woodroffe,	Runcorn.
Mitchell, James Frederick Bruce,	Bombay.
Moylan, William Morgan,	Calcutta.
Pertwee, Herbert Arthur,	Burry Port.
Richey, William Frederick Albert,	Birmingham.
Roberts, Charles Thomas,	Johannesburg.
Schloesser, Robert,	London.
Takatsuji, Narazo,	Osaka, Japan.
Tenney, Dennis,	Lincoln.
Thomasson, Lucas,	London.

Tomes, William Jameson,	London.
Turner, Henry Arthur,	London.
Wells, Sidney Herbert,	London.

ASSOCIATES.

Simpson, Edward Percy,	London.
Wadham, Arthur,	London.

GRADUATES.

Mackesy, Walter,	Wolsingham.
Simon, Ingo,	Manchester.

The following Paper was then read and discussed :—

"On recent developments in the Cleveland Iron and Steel Industries;" by Mr. Jeremiah Head, Past-President, Chairman of the Reception Committee.

At One o'clock the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in the Town Hall, Middlesbrough, on Wednesday, 2nd August 1893, at Ten o'clock a.m.; Dr. William Anderson, F.R.S., President, in the chair.

The Discussion upon Mr. Head's Paper on recent developments in the Cleveland Iron and Steel Industries was resumed and concluded.

The following Papers were then read and discussed :—

"On the Middlesbrough Salt Industry;" by Mr. Richard Grigg, of Middlesbrough. Communicated through Mr. E. Windsor Richards, Vice-President.

"Description of the Electric Rock-Drilling Machinery at the Carlin How Ironstone Mines in Cleveland;" by Mr. A. L. STEAVENSON, of Durham. Communicated through Sir Lowthian Bell, Bart., F.R.S., Past-President.

"On some Engineering Improvements in the River Tees;" by Mr. GEORGE J. CLARKE, of Stockton, Engineer to the Tees Conservancy Commission. Communicated through Mr. Thomas Wrightson, M.P., Chairman of the Works Committee of the Tees Conservancy Commission.

The remaining Papers announced for reading and discussion were adjourned to a subsequent meeting.

The PRESIDENT proposed the following Votes of Thanks, which were passed with applause:—

To the Mayor of Middlesbrough, Charles Lowthian Bell, Esq., and the County Council, for their kindness in granting the use of the Town Hall, and for their warm welcome and the facilities they have afforded in connection with this second visit of the Institution to Middlesbrough.

To the Executive Committee — and especially to the Chairman Mr. Jeremiah Head, and the Honorary Secretaries, Mr. John Dennington and Mr. Thomas Mudd—for their continuous exertions during the last eight months, which have so largely contributed to the success of the Meeting.

To the Proprietors of the Iron, Steel, Engineering, and other Works and Mines in the Cleveland district and at the Hartlepools, which have been opened to the inspection of the Members; and to the Owners of the Saltburn Gardens, for the entertainment so kindly provided by them.

To the Directors of the North Eastern Railway, and to the Tees Conservancy Commissioners, for their liberality in providing special railway and steamboat facilities for the Excursions in connection with the Meeting.

To the Committees of the Royal Exchange and of the Cleveland and Erimus Clubs, for their kindness in granting the use of the Exchange and Clubs on the occasion of the visit of the Institution to Middlesbrough; and to Messrs. Bell Brothers, Messrs. Dorman, Long and Co., and Messrs. Wilsons, Pease and Co., for their obliging accommodation in the same connection.

The Meeting then terminated at One o'clock. The attendance was 174 Members and 123 Visitors.

ON RECENT DEVELOPMENTS IN THE CLEVELAND IRON AND STEEL INDUSTRIES.

By Mr. JEREMIAH HEAD, Past-President.

The twenty-two years which have elapsed since the inhabitants of this town and district had the honour of a visit from the Institution of Mechanical Engineers have produced so many developments in the Industries of Cleveland that it would be quite impossible, within reasonable time, to deal with more than a small selection of them. In making that selection I propose to direct attention mainly to those appliances and processes which have been here devised or improved, or which have been otherwise specially identified with this district; and to give preference to what is little known over what has been fully described and widely published in the technical literature of the day.

Natural Advantages.—The Cleveland Iron industry, of which the town of Middlesbrough may be regarded as the centre, owes its rise and progress to three natural advantages, namely:—first, the existence in the Cleveland hills of ironstone, of sufficient purity and in sufficient quantity for profitable working; second, the proximity of the sea, and of an excellent navigable river affording means of communication therewith; third, the existence, at an average distance of say twenty-five miles, of the well-known Durham coalfield, which yields some of the best fuel in the world. Until these natural advantages were recognized and developed by Messrs. Bolckow and Vaughan and other pioneers, the trade of Cleveland was practically confined to agriculture. It might have remained so indefinitely, but for the opening of the Stockton and Darlington Railway in 1825, and its subsequent extension to Bishop Auckland and Middlesbrough. The new iron road afforded easy and cheap means of bringing together fuel, ore, and fluxes, and facilitating their conversion into the then much-needed rails and other railway material.

Origin and Growth of Cleveland Iron and Steel Industries.—The existence of ironstone in the Cleveland hills had long been known, but it was only in 1850 that arrangements were made for working it on an extensive scale. The primary aim and object of the Stockton and Darlington Railway, the pioneer of all railways—the successful accomplishment of which was due to the enterprise and genius of the late Edward Pease and George Stephenson, our first President—was not to facilitate iron smelting but to convey Durham coal to Stockton and Middlesbrough for shipment. When in 1839 Messrs. Bolckow and Vaughan selected Middlesbrough for their new works, they appear to have had no idea of working the mineral contents of the neighbouring hills. In 1843 we find them making marine engines for the "Rose," the first steamer ever built at Stockton. In 1846 they erected blast-furnaces, but, strange to say, not at Middlesbrough. They actually built them at Witton Park, some thirty miles inland, in the hope that the coal measures of that locality would furnish clay-band iron ore in sufficient quantities for their purpose. It was the urgent need arising from the failure of these supplies which led to incessant explorations, and finally to the opening out of the Eston mines in 1850.

The first blast-furnaces in the Cleveland district were erected by the same firm in 1852 at Middlesbrough. These were quickly followed by others at Port Clarence, built by Messrs. Bell Brothers. After that date the development of the Cleveland iron trade proceeded with great rapidity. At the time of your last visit the blast-furnaces of Northumberland, Durham, and the North Riding of Yorkshire, which I will henceforth call the North-East district, were almost exclusively occupied in smelting ironstone obtained from the Cleveland hills. I say almost, because a small proportion of foreign ores were even then imported for the purpose of improving the quality of forge and foundry grades. Official statistics show that the quantity of Cleveland ore raised in 1872 was about 6,300,000 tons, and the quantity of pig-iron made in the North-East district about 1,920,000 tons.* Although Bessemer steel was made in Great

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* British Iron Trade Association Report, 1883, p. 138.

Britain during that year to the extent of over 410,000 tons of ingots, no steel of any kind was made in this neighbourhood. The smelting of Cleveland ironstone into pig-iron; the rolling of the latter into iron rails, plates, angles, and bars, for ship, boiler, bridge, and general purposes; building of ships, engines, and bridges; making iron castings, particularly those involving heavy weights and large quantities, such as gas and water pipes and railway chairs; and constructing blast-furnace and rolling-mill plant—these were the principal industries of the district when you came to see it in 1871.

Ore is still extracted extensively from the Cleveland hills, and is still smelted into Cleveland pig-iron. It would not be fair to quote the production of 1892, because one-third of that year was virtually lost, owing to the Durham miners' strike. But taking the records of the previous year 1891, the production of Cleveland ore raised was about 5,300,000 tons, and of pig-iron about 1,493,000 tons,* or 16 and 20 per cent. respectively less than in 1871.

The Cleveland mining and Cleveland pig-iron trades have therefore to some extent lost ground during the last twenty-two years. But in addition to the above production there was made in this district in 1891 no less than 1,130,000 tons* of other kinds of pig-iron, mainly hematite, intended for the manufacture of steel. This involved the use of 2,260,000 tons of ores other than Cleveland; of which about 2,100,000 tons were imported, chiefly from Spain. Taking into account this new branch of the smelting industry, there has been an increase in production of pig-iron to the extent of about 36 per cent. as compared with 1871.

In 1872, 299,000 tons of iron rails were made in the North-East district, which absorbed about 17 per cent. of the pig-iron produced. Of plates, angles, and bars, 389,000 tons were made, which absorbed another 23 per cent., giving a total of 40 per cent. made into finished iron. The remaining 60 per cent. was used for foundry purposes or sent inland, or shipped coastwise or abroad.

The total number of works in the North-East district, which were concerned in making the above quantities of finished iron in 1872, was 37. Of these—

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* British Iron Trade Association Report, 14 Jan. 1893, p. 8.

21 have since disappeared or are now inoperative;
8 continue to roll iron only;
5 have had a steel melting and rolling plant added, and now produce both iron and steel;
3 have been altogether converted into steel works; and
3 entirely new steel works have been built: making a present total of
19 works for the manufacture of finished iron and steel.

But the size and power of production per works are now far beyond what they were at the earlier date.

In 1891 only 3,426 tons of iron rails and 268,000 tons of iron plates, bars, and angles were made in the North-East district. These figures show a loss of the iron-rail trade to the extent of nearly 99 per cent., and of the other kinds of finished iron to the extent of 36 per cent. Instead of finished iron absorbing 40 per cent. of the Cleveland pig-iron made, as in 1872, in 1891 it absorbed only about 23 per cent. And instead of having to find other markets for 60 per cent. of their produce, as in 1872, smelters in 1891 had to do this for 77 per cent. thereof, even although it was less by 20 per cent. and without taking into account the disposal of their additional produce in hematite pig.

To some extent such new markets have been found by the increased demand due to the enlargement of local foundries, and to increased consignments inland, coastwise, and abroad. But the most important new channel of consumption, and that which is of most interest to us, is the steel trade, which has arisen entirely since your last visit. Official statistics show that during the year 1891 steel ingots were produced in the North-East district as follows*:—

By the Bessemer Acid process . . .	152,748	tons
„ „ Open-hearth „ „ . . .	433,798	„
„ „ Bessemer Basic process . . .	203,461	„
„ „ Open-hearth „ „ . . .	5,480	„
Total	795,487	tons

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* British Iron Trade Association Report, 24 Feb. 1892, pp. 3 and 5.

This would be sufficient to absorb most of the hematite, basic, spiegel, and other special pig-irons which were then produced: the remainder, and the excess of Cleveland iron proper, having to be sent away for utilization elsewhere.

Having given this brief sketch of the origin of the iron and steel industries of Cleveland, and of the position to which they had attained at the time of your last visit, and having indicated in general terms how and where they have increased or diminished up to the present time, I propose to ask your attention to a few of the chief improvements which have taken place in appliances and processes since 1871.

Ironstone Mining.—In Cleveland ironstone mining, one of the principal improvements that have been effected during the last twenty years is in the mode of drilling the holes into which the explosives are placed for blasting the stone. In 1871 these holes were made by the use of jumpers driven by men working singly or in couples. The average quantity of stone so obtained was from four to six tons per man per eight hours, including drilling, blasting, breaking, and filling, and the cost varied from 10*d.* to 1*s.* per ton.

Drills.—The machine-drills now in use are of four kinds, namely:—

1st. The hydraulic turbine drill, devised by Mr. A. L. Steavenson, and in use at the Lumpsey mine near Saltburn, belonging to Messrs. Bell Brothers.

2nd. The drill driven by the Priestman petroleum engine. This also was first introduced by Mr. A. L. Steavenson, and is to be seen at the same mine.

3rd. The pneumatic drill, perfected by Mr. William Walker of Saltburn, and applied at the North Skelton and other mines.

4th. The electric drill, recently adapted and used at the Carlin How mine by Mr. A. L. Steavenson.

The principle adopted in all these four cases is that of rapidly rotating an auger-shaped drill, fixed in an adjustable frame, and supported upon a bogie which is capable of being advanced towards the working face and withdrawn, as found necessary. The hydraulic turbine drill is driven by water at a pressure of 140 lbs. per square inch, obtained from a feeder tubbed back in the shaft, and brought to the machine by suitable piping. For the pneumatic drill, air at a pressure of 55 lbs. per square inch is similarly brought from a reservoir and compressors at the surface.

Whatever be the motor, the rapidity of drilling depends on the amount of power applied and the energy and expertness of the men in pushing forward the work. The hydraulic drill has the advantage that the requisite motive power is obtained at the mere cost of pumping up to the surface the water exhausted by the turbine. The petroleum drill has the advantage that neither air nor water supply-pipes are needed; and the pneumatic drill, that it assists the ventilation. A pneumatic drill attended by sixteen men will obtain from 800 to 1,050 tons of ironstone per week of 45 hours, which is equal to an average production of $10\frac{1}{4}$ tons per man per shift of 8 hours, or about twice the weight obtained by hand jumpers. The cost of getting is from 8*d.* to 10*d.* per ton, or about 2*d.* per ton less than formerly. These machines are capable of drilling a $1\frac{3}{4}$-inch hole 4 feet to $4\frac{1}{2}$ feet deep in about a minute. In practice 80 to 85 holes are drilled in 8 hours. As the electric drill forms the subject of a separate paper by Mr. Steavenson (page 309), it will not be necessary to say anything further about it here.

The hand ratchet-drill manufactured by the Hardy Pick Co. of Sheffield takes a position intermediate between the old jumpers and the machine drills, and is well worthy of notice. It has of late been brought into use in several of the Cleveland mines. It is cheap in first cost, and easy to fix, especially in awkward positions where no other tool would be applicable. No complications in the way of pipes or conductors are required, nor any fuel supplies. Mr. William Charlton, engineer at Sir B. Samuelson and Co.'s Slapewath mines, has made some improvements in the details; and by aid of these nearly as much stone per man per shift can be obtained as with machine-drills proper.

The North Skelton, the deepest of the Cleveland mines, extends to 120 fathoms below the surface. Nevertheless there is no great quantity of water to contend with, 100 gallons per minute being about the average. For ventilation the Guibal fan is the one generally preferred. The largest, namely that at Eston, is 40 feet in diameter by 12 feet broad, and delivers from 120,000 to 140,000 cubic feet per minute.

Nature of Ore.—At the Cleveland mines the "Main seam," namely, that first opened out by Mr. John Vaughan, which is from 10 to 16 feet thick, is the only one worked at present. There are other seams above and below, but they are much thinner. The proportion of metallic iron in the raw stone varies from about 26·5 to 31·75 per cent. The general average may be taken at about 28·5 per cent. When calcined the ore yields from 38·0 to 43·5 per cent. of metallic iron, or about 40 per cent. on the average. The phosphorus in the raw stone varies from 0·4 to 0·8 per cent., averaging about 0·6. The sulphur averages 0·12 per cent. The duration of the best deposits is estimated at from fifty to sixty years. The quantity of inferior stone is as yet undetermined, but is no doubt very large.

At the Liverton, Lingdale, and Stanghow mines, the contents of the tubs as they come from the pit are tipped upon moving belts of considerable breadth, which carry the stone forward to the trucks. All shale, dogger, and other impurities are thus easily seen and picked out by boys placed there for the purpose. This plan enables the quality of the ore to be greatly improved.

Blast-Furnaces.—In 1878 the late Mr. Thomas Whitwell stated, in the course of a paper upon blast-furnaces which he read before the Cleveland Institution of Engineers (Proceedings 1877–78, page 135), that the average Cleveland furnace was then 80 feet high, 23 to 25 feet diameter at the bosh, and 8 feet diameter at the hearth. The average temperature of the blast was 850° Fahr., and the consumption of fuel 23 cwts. of coke per ton of pig-iron. He gave the blast pressure as varying from $2\frac{3}{4}$ to $4\frac{1}{4}$ lbs. per square inch. From other sources I find that the average make of pig-iron per furnace in 1872 was under 300 tons per week. Some furnaces however, almost as large as any since built, were then in operation: notably two at Messrs. Wilsons, Pease and Co.'s works, 85 feet high by 27 feet bosh and 9 feet hearth, built under the supervision of Mr. Charles Wood in 1869; and two at Sir Bernhard Samuelson's Newport Iron Works, built to the designs of Mr. R. Howson in 1871, 85 feet high by 28 feet bosh and 8 feet hearth, and having a capacity of 30,085 cubic feet. In a paper read before the Iron and Steel Institute in 1887 (Journal part 1, page 91), Sir Bernhard gave the average production of these furnaces at 490 tons each per week, and the consumption of coke at 20·35 cwts. per ton of pig-iron, with calcined ore containing 43·5 per cent. of iron. It appears however that their consumption rose subsequently to 23·48 cwts., but was again reduced by 3·89 cwts., namely to 19·59 cwts. per ton of pig, by the substitution of fire-brick for pipe stoves, and the use of better fuel.

Since 1871 no great change has been made in the size, form, or performance of the then best designed furnaces using the best materials; but much better average results have been obtained than those named by Mr. Whitwell. This has been brought about by the reconstruction since that year of almost all the older furnace plants, thus raising the average efficiency to the level of previously exceptional performances. A weekly output per furnace of 500 tons of Cleveland or of 800 tons of hematite pig is no longer considered remarkable; and even these figures have been considerably exceeded.

The best performance which has come to my knowledge as regards any furnace on Cleveland iron is that obtained by Messrs. Cochrane and Co. at their Ormesby Iron Works. One of their furnaces, 90 feet high by 23 feet bosh and 10 feet hearth, is producing on the average 700 tons of pig-iron per week. Two others, 90 feet high by 29 feet bosh and 10 feet hearth, produce each an average of 825 tons. In one particular week no less than 949 tons was obtained from one of these furnaces, which, as regards cubic capacity, are the largest in Cleveland, and perhaps in the world.

The effect of the internal shape of blast-furnaces upon their power of production has lately been engaging the consideration of Mr. William Hawdon and Mr. Richard Howson, of the Newport

Iron Works. In furnaces made of the ordinary shape they point out that the whole weight of the charge rests upon the inverted conical surface of the bosh and upon the hearth, the consequence being that the descending charge becomes tightly packed at the region where it is in a semi-fused or plastic condition. This causes difficulty in forcing the blast through, and delay in the process of reduction. The remedy they propose is to alter the internal form in such a way that the materials shall be sustained in the upper part of the furnace, where they are as yet in a solid and open condition; while lower down the internal form will be such that the charge shall be able to descend more freely than at present, and shall thus become more permeable to the blast. One of the Newport furnaces working on Cleveland ironstone has been altered on this principle, with the result that an increase in output of from 30 to 50 per cent. has been obtained, together with a higher average grade of iron and some saving in coke.

The average output of pig-iron per furnace per week in the North-East district during the year 1891, including hematite, basic &c., was 548 tons.* The consumption of coke per ton of pig-iron has fallen from 23 to 20 cwts. and even below for Cleveland, and to 19 cwts.† and below for hematite, where good ore and fuel are used; though probably it still remains at the higher figure where the conditions are less favourable.

It is alleged by some authorities on blast-furnace management that neither the Cleveland ironstone nor the Durham coke are so pure as they used to be. This is believed to be partly owing to the exhaustion to an appreciable extent of the best mineral beds, and the consequent admixture of less pure materials. It is not infrequently asserted that, whatever advantage in blast-furnace economy has been obtained by improved appliances and processes, has been to a great extent neutralized by deterioration in the quality of the minerals supplied.

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* British Iron Trade Association, Bulletin No. 23, 1893, pp. 1 and 3.

† Cleveland Institution of Engineers, Proceedings 1890–91, p. 182.

Hot-Blast Stoves.—The increased average output per furnace working on Cleveland ironstone, and the lessened consumption of fuel—where the best qualities are used—seem to be largely due to the higher temperature of blast rendered possible by the adoption of fire-brick instead of pipe stoves. In 1871 the only fire-brick stoves in the district were:—those devised by the late Mr. Edward A. Cowper, Past-President, at the works of Messrs. Cochrane and Co., who, acting under the advice of Mr. Charles Cochrane, Past-President, led the way in this great improvement; those at the works of Messrs. William Whitwell and Co. of Thornaby, who adopted their own particular type in 1869; and those at Consett, which, being erected under the supervision of the late Mr. Thomas Whitwell, were of the same kind. At the present time fire-brick stoves are almost universal, there being only two works without them. At first they were made 28 feet high by 22 feet diameter, and two were thought sufficient for one furnace. Now they are made 60 to 80 feet high by 22 to 26 feet diameter; and three, four, and even five are worked to a furnace. The temperature of the blast has risen from an average of 850° Fahr. to about 1,450°; and the pressure from an average of 3½ lbs. per square inch to 5¼ lbs. in Cleveland and 6½ lbs. in hematite furnaces, and even higher.

Blowing Engines.—At your last visit, a paper was read by the late Mr. Alfred C. Hill on the compound surface-condensing blast-engines (Proceedings 1871, page 175), which had then recently been erected to his designs by Messrs. Kitson and Co. at the Lackenby Iron Works. These engines are still in operation; but until quite lately there has been little extension of fuel-saving expedients as applied to blowing engines since that time. This is probably owing to the circumstance that all necessary steam can usually be obtained from the combustion of the furnace gases, at all events when Cleveland ironstone is being smelted. The favourite blowing engine in the district is still the inverted non-condensing type, which has the advantage of great simplicity and compactness. Wherever hematite came to be substituted for local ores, the furnace gases were found to be of much poorer quality, owing mainly to their dilution by the steam from the water mechanically and chemically combined in that class of ore. Consequently where hematite ore is smelted, steam must now be economized, if it be desired to avoid the use of extra fuel at the boilers. Inasmuch also as all feed-water used in Tees-side works is pumped from the river at Darlington, and paid for by meter at 3*d.* per 1,000 gallons, the saving of water as far as possible is a consideration, as well as the saving of fuel.

The methods which have been recently adopted for economizing in blast engines are three: namely feed-heating, condensing, and compounding. A very complete example of all three methods is afforded by the new plant at Messrs. Cochrane and Co.'s works. Three non-condensing blast-engines exhaust into one common main. From this, steam is taken by a fourth engine, which exhausts into a surface-condenser. The circulating water for the condenser is drawn from and returned to the river. From the exhaust-main a portion of the remaining steam passes into a series of Berryman evaporator-condensers, in which it is condensed, and becomes again available as feed-water. In its condensation it gives up its latent heat to the circulating water, which is from the Darlington mains; and from this it distils feed-water to make up some of the waste. The exhaust steam however would soon heat up the circulating water to its own temperature of about 212° Fahr., and further condensation would thereupon cease, were it not for another expedient. The space above the circulating water is connected by a pipe with another Berryman condenser, cooled by river water, and beyond this with an air-pump. Thus the Darlington circulating water is under a vacuum, and consequently evaporates at a correspondingly low temperature; it is therefore able to condense steam at atmospheric pressure and to become itself gradually distilled. In this way out of the 75,000 gallons per 24 hours evaporated by the boilers, only 12,500 gallons, or say one-sixth of the total, has to be supplied and paid for anew. The feed-water thus obtained is forced through a series of Edmiston filters to free it from grease and other impurities, then through another Berryman heater, utilizing the remainder of the steam from the exhaust-main, and so into the boilers. The pressure in the exhaust-main varies from between ½ and 1 lb. below to between ½ and 1 lb. above the atmosphere. The temperature of the feed as it enters the pumps is 110° Fahr., and as it enters the boilers 210° Fahr.

Another application of compounding and condensing to blast-engines is that recently carried out at Sir B. Samuelson and Co.'s works by Mr. Tom Westgarth, under the direction of Messrs. Hawdon and Howson. Of four non-condensing blowing engines of usual construction, one remains untouched; a second has had a jet condenser and air-pump fitted; the third and fourth have been compounded by the addition of extra cylinders, and have had similar condensers added. The condensing water is separately pumped from and returned to the river, a water tower intervening. The amount of economy obtained has not yet been accurately determined; but Mr. Westgarth claims that one boiler in six has been dispensed with, without diminishing the output of pig-iron and without using any fuel specially for evaporation. At the Skinningrove Iron Works two blowing engines work together, forming one compound jet-condensing engine, but they can be used separately if necessary. Messrs. W. Whitwell and Co. have a simple jet-condensing blowing-engine; and there is one with a Morton's ejector-condenser at the Cargo Fleet Iron Works. All others in the district are simple non-condensing engines.

Boilers.—As regards blast-furnace boilers, in 1871 they were almost exclusively of the plain cylindrical type, 80 feet long by 4 to 5 feet diameter, and rigidly supported. These were found to strain themselves at every change of temperature, and to be far from safe. In some cases they were cut in two in the middle of their length, and connected by a short pipe. In others they were hung on volute springs on the plan suggested by the author.* The elephant type first introduced by Mr. Charles Wood was substituted at the Tees Iron Works, and also to some extent at the Thornaby Works, with good results. The Howard boilers at the Lackenby Works were found unsafe, and others of the Lancashire type were substituted.

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* Iron and Steel Institute Journal, 1871, part 1, page 64.

Messrs. Cochrane and Co. still work Root's boilers, and have done so for eighteen years; but their use has not extended further. Only the purest water can be used; they are expensive to keep up, and require extra attention on account of the fluctuations due to the small body of water contained in the tubes. They also require some coal to be always burning as a wick for keeping alight the entering gases. The favourite boiler for furnace plants is now the three-flued Beeley boiler, which is a simple, compact, and efficient steam-raiser. In boilers of all kinds, the material used, the mode of construction and mounting, and the fittings have been greatly improved during the last twenty years.

Comparison with American Blast-Furnaces.—On the occasion of the visit of the members of the Iron and Steel Institute to America in 1890, most engineers and ironmasters from this district were deeply impressed by the enormous outputs obtained per furnace at some of the American smelting works. This was found to be due in a large measure to the use of exceedingly rich ores; but that did not altogether account for the observed results. Mr. James Gayley, one of Mr. Carnegie's managers, has since published the performance of the Edgar Thomson furnace "I" during January 1892.* This furnace is 90 feet high by 21 feet bosh and 12 feet hearth, and has a capacity of about 23,000 cubic feet. The make during the month was 12,706 tons, the average yield of the ore 61 per cent., the coke consumption 1,700 lbs. or about 15 cwts. per ton of pig-iron, the best week's work 3,005 tons, the best day's work 511 tons, the temperature of blast 1,200° Fahr., and the pressure 10½ lbs. per square inch. The volume of air delivered by the blowing engine was 27,000 cubic feet per minute, which is 1,175 cubic feet per 1,000 cubic feet capacity, or from 3 to 4½ times what is usual in Cleveland. As regards the advantage obtained by richer ore, that is clearly unattainable here, if local ores only are used. As regards difference in practice, the most noteworthy thing is the enormously greater quantity of air passed through the American furnace than is customary here, and the higher pressure of blast which has to be maintained for enabling it to penetrate the charge. The circumstance that the maximum American output exceeds the Cleveland maximum in about the same proportion as the air passed through per 1,000 cubic feet of capacity seems in some measure to explain these wonderful results.

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* Iron and Coal Trades Review, 28 Oct. 1892, page 570.

Although the American practice of forcing furnaces, with the consequent rapid destruction of linings, has not found favour generally in Cleveland, still it has raised much discussion and indicated various lines of progress for the future. In America great stress is laid upon large blowing power, and upon blowing every furnace from a separate engine or engines, independently of any others. The quantity of air entering a furnace is regulated by the number of revolutions per minute which the engines make, without regard to the blast pressure obtained. The engines are indeed used as air-meters as well as air-pumps. Each one is provided with a governor, which keeps it approximately at a uniform speed, however much the resistance may vary. An ingenious centrifugal speed-recorder by Mr. Edward Brown of Philadelphia is employed as a check, and has since been introduced here by Messrs. William Whitwell and Co. Cleveland engineers as a whole are still unconvinced that separate blowing is better for their circumstances than blowing into and drawing out of one common main; but nevertheless arrangements have in some cases been made to give the power of separate blowing as in America. At one works a special furnace has been built to use Spanish hematite on the lines of the most recent American practice; but sufficient experience has not so far been obtained for enabling deductions to be made. The lining of a Cleveland furnace lasts any time from six years * if on hematite, up to eighteen and even twenty years if on Cleveland. One of Messrs. Cochrane and Co.'s furnaces, which has just been re-lined, lasted nearly eighteen years and served for 500,000 tons of pig-iron. The American highly-forced furnaces require re-lining in

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* Proceedings Cleveland Institution of Engineers, 1890–91, p. 180.

two or three years,* which would scarcely admit of such a production as this per lining.

Pyrometer.—The perfect control of smelting operations has hitherto been rendered impossible or difficult, for want of an instrument capable of indicating high temperatures with accuracy. Such an instrument can now be obtained in the Le Chatelier pyrometer, on which a paper was read before the Cleveland Institution of Engineers in November last (Proceedings 14 Nov. 1892, page 25) by the Mayor, Mr. Charles Lowthian Bell. A thermo-electric couple of platinum and platino-rhodium wires is inserted permanently in the blast main or in any of the gas downcomers, and is connected by conductors with a galvanometer placed in the manager's office. The galvanometer, by means of a twisting mirror, causes a beam of light to fall upon a scale, from which the temperature is read off. On the improved plan devised by Professor Roberts-Austen, the beam of light, instead of falling only upon the scale, is caused to act on sensitized paper coiled on a clock-driven barrel. On this it traces a continuous curve recording autographically every change of temperature. A complete check is thus provided day and night upon the operations of the furnace-men; and a clue may be obtained to the cause of troubles, and their remedy be facilitated, in a way which otherwise would not be possible.

Slag Disposal.—In 1871 little had been done in the way of utilizing any of the slag made in Cleveland, which now amounts to $3\frac{3}{4}$ million tons annually. Various unsightly mountains were being piled up on land dearly purchased for the purpose. The river improvements absorbed a certain proportion, and road-making and levelling up waste land a further quantity. On the completion of the South Gare breakwater, it was found absolutely necessary to organize a barge service, whereby the slag might be sent out to sea, in those cases where there were no other means for disposal. The slag balls as then made weighed from 2 to 4 tons each, and were naturally difficult to deal with. Various plans were devised for breaking them up to facilitate loading. But it has since been found better to adopt means by which the slag is never allowed to accumulate in a heavy mass at all. Mr. Hawdon's ingenious arrangement whereby the liquid slag is converted into solid shingle, and at the same time loaded up into trucks, has been recently brought before the Institution (Proceedings 1892, page 70). By means of this plant, which is being extensively adopted, the removal and loading of the slag goes on continuously and automatically at a cost of about 1·3 penny per ton of slag removed, or 2·8 pence per ton of pig-iron.

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* Proceedings Cleveland Institution of Engineers, 1890–91, p. 177.

Slag Wool.—Slag wool, with the invention of which Mr. Charles Wood's name has always been associated, is still manufactured under his supervision at Messrs. Wilsons, Pease and Co.'s works on a considerable scale. It is produced by blowing jets of steam across fine streams of molten slag as they issue from the furnace. The wool, which is really a matted mass of fine spun glass, is used for a variety of purposes, of which the one that is perhaps of most interest to engineers is as a non-conductor of heat. Mr. S. W. Johnson, Member of Council, locomotive superintendent of the Midland Railway, states that he has used it for several years on locomotive boilers with excellent results. The total quantity produced at the Tees Iron Works exceeds 1,000 tons per annum.

Paving Blocks.—About twenty years ago it was discovered by Mr. Woodward that blast-furnace slag run into an iron mould and then annealed would make an exceedingly hard and tough block suitable for road paving, and much cheaper than setts of granite or other natural stone. The manufacture of these blocks is now carried on at three of the Cleveland smelting works, by the Tees Scoriæ Brick Co., and has become one of the staple industries of the district. Some only of the slag as it comes from the furnace is of suitable quality; and therefore the selected produce of five furnaces is required to produce a daily average of about 10,000 blocks. The total produce of the district is at present about 100,000 blocks per week, of a value of about 13*s.* per ton or 75*s.* per 1,000 blocks of ordinary size.

The process of manufacture is as follows. The slag, when coming from the furnace of suitable quality, is run into a bogie ladle. From this it is poured into cast-iron moulds secured to the periphery of a horizontal wheel. Each mould has a hinged bottom. The wheel is slowly rotated, and the bottoms of the moulds are released in succession. The blocks, molten inside but chilled and solid at the surface, drop upon a soft bed of granulated slag, and are quickly removed and stacked in an annealing stove. When full, the doors of the stove are closed, and the blocks are allowed to anneal themselves without any extraneous heat. In about eight hours the doors are opened, and the blocks gradually withdrawn. They are then fit for use. Without annealing they would soon crumble to pieces from internal stresses. The waste, owing to unsuitable slag and other difficulties, averages 30 per cent. of those cast. About twenty different sizes and shapes are made to suit customers' requirements. The blocks are in great demand for street paving, not only locally, but also in many foreign towns where they can be cheaply conveyed by water. They find their way even to Canada. The cost of paving with them, exclusive of labour and freight, varies from 2*s.* to 3*s.* 7*d.* per square yard.

Hydraulic Cement.—Among the uses to which Cleveland blast-furnace slag has been recently applied, the manufacture of hydraulic cement ought to be mentioned. The fact that slag contains all the elements of a good hydraulic cement, except that there is a deficiency of lime, was long since noticed; and many experiments have been made by Mr. Charles Wood, Mr. J. E. Stead, and others, to ascertain whether it could be manufactured into this useful material. The construction of a pier near the Skinningrove Iron Works afforded recently an excellent opportunity of putting the idea into practice. Mr. T. C. Hutchinson, the managing director of the works, aided by Mr. W. Kidd, his engineer, succeeded in carrying the manufacture to complete success. The pier was constructed of concrete walls made of slag cement and backed up with slag rubble. Although these works are situated on an unprotected part of the coast, the owners have been able, since the construction of the pier, to ship their produce as easily as if they had been situated on the banks of the river Tees. Slag cement is made by running a stream of slag into water, whereby "slag sand" is formed. The latter, after being dried, is pulverized by millstones, and then introduced into an iron barrel on gudgeons, containing a number of iron balls. Lime, which has been previously slaked and dried, is added, and the barrel is rotated until the ground and mixed contents resemble fine flour, and are capable of passing through a sieve containing 180 wires per linear inch without leaving a residue of more than 10 to 15 per cent. This fine powder is slag cement. Its analysis does not differ greatly from that of Portland cement, except that it has more alumina and silica and less lime. Its present cost is about 25*s.* per ton, or rather less than Portland cement. Test pieces composed of 3 parts of sand to 1 part of cement have, after standing a month, a tensile strength of 361 lbs. per square inch. It has a remarkable power of setting quickly under water.

Pavement Flags.—Another important industry which has sprung up in the North-East district in connection with the utilization of slag is the manufacture of artificial pavements. Twenty years ago, natural flag-stones from Caithness and elsewhere were almost universally used for side-walks, and Yorkshire landings from Bradford for railway platforms. All that is now altered. For railway platforms, cement concrete, which may or may not have slag or slag cement in its composition, is used with excellent results; and similar pavements are to some extent used in this and other towns for side-walks. But the manufacture of artificial flags is, to a great extent, an industry peculiar to this district. They are made about 2½ feet square by 2 inches thick, in suitable moulds, from ground slag mixed with Portland or slag cement as previously described. In some cases the top surface is composed of the residue from the manufacture of annealed slag-blocks, which, it is claimed, is harder and more durable than concrete made from other materials. After being moulded, the flags are stacked for some weeks before they are fit for use. Pavements made from artificial flags are far more smooth, level, and uniform than those made from natural flag-stones, as will be seen by anyone who inspects the pavement surrounding the Middlesbrough Town Hall.

Although this has been in use for several years, there is no sign of deterioration, especially of that lamination through wet or frost which is so destructive to the appearance and utility of natural flags. Concrete in separate flags is less likely to crack, and is more easily adjusted in case of subsidence, than where large areas are covered without subdivision. The cost per square yard is now about 3*s*. 8*d*.

Finished Iron.—The finished-iron trade in this district, as already shown (page 227), has been steadily diminishing since 1872, owing to the almost complete supersession of iron rails and of iron ships and boilers by those constructed of steel. It is still a debatable question whether this supersession will continue further or not. The superiority of steel in the way of strength, ductility, and homogeneity is so universally recognised, that it is not likely to be to any considerable extent ousted by its old rival, wrought-iron. But the latter has some undeniable physical advantages, besides being still rather cheaper than steel. It is more easily welded; and it does not become corroded so rapidly in positions where protection by paint is not easily maintained. The former advantage is probably the reason why it continues to hold its own in bar mills; for country blacksmiths, the principal users of bar iron in all countries, will have what they can readily weld. The latter advantage accounts for its persistence in roofing sheets and in plates intended for the internal parts of ships. Although 94 per cent. of the ships now built are nominally of steel, iron is still preferred and used by many builders and owners for internal parts, such as deck plates, bunkers, engine and boiler seatings, floors, bulkheads, etc. In some of these parts no reduction in thickness is allowed by Lloyd's Committee for using steel; and therefore the lower price of iron tells in its favour, as well as its less liability to corrosion. For these reasons iron bar and plate mills still exist, although in diminished numbers; and they seem likely to continue for some time to come.

The puddling processes and the appliances used therein remain almost exactly as they were in 1871. Numerous improvements have been devised and tried, but they generally led to difficulties with the operatives, and were ultimately abandoned. An important advance in the manufacture of finished iron has been made by the introduction or rather development of separate blooming-mills. A finishing mill formerly received a pile direct from the heating furnace, and after numerous passes produced a finished bar or plate. This occupied the whole mill a considerable time for a small produce. Re-heating was usually resorted to for heavy sections after the first few passes; but nevertheless the same mill or train did all the reducing. Separate mills are now employed for the earlier passes. Such mills can bloom a far greater weight of piles in a given time than can a finishing mill if so employed; and the finishing mills, being confined to their own proper use, become able to turn out a much larger tonnage. Separate blooming-mills are usually made capable of receiving piles of much larger sectional area than were formerly dealt with. By this means the proportion of scrap-iron contained in the pile can be increased, and the total requisite improvement in quality can be obtained by more abundant work on the iron, rather than by costly mixtures in the puddling furnace. Thus the productive power of finishing mills has been largely increased, and the cost of production lessened, without any deterioration of quality.

Mill Engines.—In the plate-mills of the district great advantage has also been obtained by the use of more powerful engines than were formerly thought necessary. One of these, designed by the author and constructed by Messrs. Westgarth, English and Co. in 1885, is working a plate-mill at Messrs. John Hill and Co.'s works, the production of which averages 750 tons per week. It has a single cylinder, 48 inches diameter and 54 inches stroke, both cylinder and covers steam-jacketed, works with a pressure of 60 lbs. per square inch, and is fitted with an automatic variable expansion-gear and with a steam-actuated starting-gear.*

At the Bowesfield Iron Works a powerful reversing engine, with two 36 × 42 inch cylinders and geared in the proportion of 3 to 1, was constructed to the author's design by Messrs. Miller and Co. of Coatbridge in 1888, for the purpose of driving a heavy plate-mill and separate blooming-mill. In this case the plate-mill was driven from one end of the second-motion shaft and the blooming-mill from the other. In handling the engine, preference was always given to the plate mill, and the blooms were put through the other mill just as opportunity arose. Experience showed that neither mill interfered with the other in the least. The advantages of separate blooming were therefore obtained without a separate engine or attendant. On the starting of this reversing engine the make of the plate mill rose from 300 up to 570 tons of finished plates per week. *

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* "The Engineer," 6 May 1887, pages 349, 352, 360.

Other improvements have been made in finished-iron mills, such as larger and more powerful shears, capable of cutting up to 1½ inch and even 2 inches thick, and having gaps as deep as 30 inches. The application of double-cylinder reversing-engines to plate shears, of sufficient power to cut any thickness without the aid of a fly-wheel, has been a further advance. Also the employment of steam winches for hauling the plates about on the cooling-floors, and of similar apparatus for turning them over for examination, and for charging piles into, and drawing them out of, heating furnaces; and the use of lamps on the "lucigen" principle, to facilitate shearing by night. All these improvements have had a share in cheapening the production of wrought-iron, and in enabling it to resist extermination by the ever-increasing competition of steel.

Corrugated Sheets.—The manufacture of galvanized corrugated sheets was introduced into Middlesbrough about three years ago by Messrs. R. P. Dorman and Co. Some difficulty was at first encountered in obtaining the requisite skilled workmen; but now they are able to make corrugated sheets of a quality equal to those produced in Staffordshire and South Wales. The output of this firm is about 200 tons per week, all of which finds a ready market in India, China, the colonies, and elsewhere.

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* "The Engineer," 15 Feb. 1889, page 144.

Steel Manufacture.—By far the most important addition to the industries of Cleveland since 1871 is the manufacture of steel. As already stated (page 227), this admits of four divisions, namely the Bessemer and the open-hearth acid processes, which deal with hematite pig-iron made in the locality from Spanish ore; and the Bessemer and the open-hearth basic processes, which deal with special pig-iron containing a considerable proportion of impurity, and made from local ores and cinders. In the two acid processes, the conversion of the pig-iron into steel takes place in vessels or hearths having silicious or acid linings. In the two basic processes, the linings are composed of lime, magnesia, or other basic material. Although open-hearth basic furnaces have been tried in the district, there are none in operation at present. This process therefore cannot as yet be considered of practical importance here, although it might become so at any time, were there anything to interfere with the supply of hematite ore from Spain.

The favourable position of Cleveland for the importation of Spanish ore has naturally led to the development of the acid processes far more than of the basic. In Germany, on the other hand, which is not so favourably situated for obtaining hematite ore, the basic processes have been relatively far more developed. There are those who think that we in Cleveland have been less wise than our German competitors in this respect, for our own steel trade is not self-contained, whilst theirs is so. But however that may be, we have at present only two works where the basic process is in operation, namely the North Eastern Steel Works, and Messrs. Bolckow, Vaughan and Co.'s Eston Steel Works. Both of these establishments have been constructed since 1871. Their finished products consist of rails, steel sleepers, tin bars, blooms, and billets. Messrs. Bolckow, Vaughan and Co. have appliances for working on all four processes, but at present are confining themselves to the Bessemer acid and Bessemer basic. The North Eastern Steel Co. use the Bessemer basic process only.

Mixing and De-sulphurizing.—At the Eston Steel Works the combined mixing and de-sulphurizing apparatus, first introduced by Mr. Joseph Massenez of Hoerde, has recently been adopted by

Mr. David Evans. Two mixers have been erected, each capable of holding 120 tons and together of dealing with the make of four blast-furnaces, or about 2,000 tons of pig-iron per week. The pig-iron is of ordinary Cleveland quality, containing not more than 1½ per cent. of silicon and an average of 1 per cent. of manganese, which however is concentrated mainly in the product of one furnace. The principle acted upon is that the iron sulphide in the pig-iron is decomposed in the mixer by the manganese, producing manganese sulphide which flows off in the slag, and leaving metallic iron free from sulphur. Analyses show that rails made by the Bessemer basic process from Cleveland iron so treated cannot practically be distinguished from those made by the Bessemer acid process from Spanish hematite ore. Inasmuch as it costs £50 to line a Bessemer basic converter, it is of course important to make the linings last as long as possible; and by the use of low-silicon pig and subsequent de-sulphurization, Mr. Evans has succeeded in obtaining fifty blows per lining, as against thirty formerly. A mixer has also been erected at the North Eastern Steel Works.

A process has been devised by Mr. E. H. Saniter of Wigan for effecting de-sulphurization by introducing into the receiving ladle 25 lbs. of calcium chloride and an equal weight of lime per ton of pig-iron. Experiments on this process have been tried at the Newport Iron Works; but so far it has not been introduced commercially into this district.

It would be superfluous to dwell on the Bessemer processes, acid or basic, as they are so well known. It may be mentioned however, as one of the staple industries of the district connected with the manufacture of steel, that Messrs. Bolckow, Vaughan and Co. now produce extensively at their Middlesbrough works ferro-manganese and spiegel-eisen, importing the requisite manganese and manganiferous ores from the Caucasus, Levant, and elsewhere.

Re-carburizing.—Mr. J. H. Darby's interesting process of re-carburizing steel by dissolving therein powdered carbon obtained from anthracite, gas carbon, or other sources, has been adopted to some extent in the Cleveland steel trade. Should the basic processes extend, this invention will no doubt come still more into use. At present however, the bulk of the steel made being by one or other of the acid processes, there is no difficulty in obtaining the requisite percentage of carbon, without any special introduction of that element.

Basic Slag as Manure.—The slag resulting from the Bessemer basic process has been proved to possess valuable qualities as a manure, owing to the large percentage of phosphorus which it contains. As a tetra-basic phosphate of lime, in which form the element is present, it can be readily assimilated by plants, provided the slag is ground sufficiently fine. At the North Eastern Steel Works a large milling plant has been erected, in which the whole of the slag, amounting to 25 per cent. of the total weight of steel produced, is ground by edge-runners or other means, until about 83 per cent. will pass through a sieve of 120 wires per linear inch. It has been found by experiment that the efficiency of the manure is not increased by grinding it finer than this. Any small fragments of steel which may have become mixed with the slag are removed by magnets. The manure contains from 17 to 20 per cent. of phosphoric acid, 50 per cent. of lime, and 14 per cent. of iron oxides, together with smaller quantities of other ingredients. Exhaustive experiments have been made with the manure in this and other countries. It has been found most effective when mixed with other nitrogenous manures in the proportion of 4 to 1, and when 5 cwts. of the mixture is used per acre. It is then about equal to superphosphate in beneficial effect. At the price of 27*s.* per ton it commands a ready sale.

Heating Furnaces for Steel Ingots.—In furnaces for heating steel ingots, an improvement of great importance has recently been made by the adoption of so-called vertical furnaces. These seem to be a development of Mr. John Gjers' "soaking pits," wherein the internal heat of semi-solidified ingots was utilized by placing them vertically in fire-brick pits, until an average temperature suitable for rolling was attained. The modern vertical ingot-heating furnace resembles a group of such soaking pits, with additional facilities for heating the charge externally. For this purpose producer-gas is usually, though not of necessity, employed. The vertical furnace has the advantage that a powerful overhead crane is easily applied for charging and withdrawing the ingots, and another smaller one for removing and replacing the covers. A pair of hydraulic radial cranes are sufficient for twenty or more pits, if the latter be arranged in a circle around them. No manual labour is necessary beyond controlling the cranes, adjusting the lifting tongs, and occasionally removing accumulations of flue cinder. The larger crane is sometimes a steam traveller, in which case it can act for an unlimited number of pits. The new vertical furnaces at Messrs. Dorman, Long and Co.'s works, and also those at the Eston Steel Works, have been made on the regenerative principle, whereby much higher temperatures than ordinary are attained, with consequent saving of time. In these furnaces the pits communicate with one another, forming one large heating chamber. The direction of the flame is reversed every half hour.

When first the steel trade was introduced into the North-East district some years ago, it became obvious that much heavier weights in the way of ingots would have to be dealt with than had previously been necessary in the way of piles or blooms. The plan most in favour at first was to bring lines of railway into and throughout the works, using thereon locomotives and bogies or self-moving cranes. By means of these, ingots, slabs, and blooms could be taken from the furnaces to the mills, while the same appliances could also be utilized in charging and drawing. This plan is still much in vogue, especially where the works have not been originally laid out for steel-making, and where the route from the furnaces to the mills is long and circuitous. In such cases narrow-gauge railways with miniature locomotives are found very convenient, because of the small space they occupy and the sharp curves which they admit of. In modern works, specially designed for steel-making, the tendency is so to lay them out that hydraulic cranes and live rollers perform all the necessary moving of heavy weights. This is best accomplished by placing the vertical furnaces, cogging mill, hot shears, heating furnaces, finishing mill, and saws as far as possible in series, so that the pieces run in a straight line or nearly so from the ingot-heating furnace to the loading bank.

Cogging and Finishing.—Cogging and finishing are now almost invariably done by powerful reversing engines, on the plan first adopted thirty years ago by Mr. John Ramsbottom, Past-President. In cogging and plate mills gearing is always used. Finishing mills for rails or section-bars are worked direct. In the earlier days the finishing engines had a mill on each side. This plan is still occasionally adopted, but in that case the mills are worked alternately and not simultaneously. While one mill is working, the rolls are being changed at the other. For every mill to have a pair of engines exclusively to itself when working, is the system which has slowly been evolved.

No reversing rolling-mill engines in the North-East district are compound, nor are any condensing. Though hunting gear is sometimes applied to the reversing apparatus of the larger engines, it is seldom if ever used for expansive working, notwithstanding the importance of saving steam where raised in coal-fired boilers. It is a rather curious circumstance that half a century ago large rolling mills were almost always driven by condensing engines worked to some extent expansively. Now such engines are all non-condensing, and for the most part work almost non-expansively. This seeming retrogression is held to be justified by the intermittent character of the work, the necessity for frequent reversals, and for applying maximum power at starting, whatever the position of the cranks. The desirability of simplicity in all rolling-mill machinery is also generally pleaded. The employment of a separate condenser and air pump, for the use in common of all the engines in a mill, has often been suggested. Hitherto the plan has not been carried into effect, because of the relatively large quantity of cooling water which is required to maintain a continuous vacuum under intermittent conditions. A plan for working reversing rolling-mill engines to some extent expansively was submitted by the author to the Cleveland Institution of Engineers in February last (Proceedings 20 Feb. 1893, page 121).

Steam Pressure.—The pressure of steam adopted in steel works is from 80 to 100 lbs. per square inch, instead of 35 to 60 in the finished-iron works. Lancashire boilers are now almost universally used, and the plain cylinder and Rastrick types will soon be things of the past. Mechanical stokers are increasingly in favour, being much more regular in action and generally more manageable than the human variety.

Hydraulic Power.—Hydraulic power, for which the accumulator pressure is usually about 700 lbs. per square inch, is being more and more used. Besides being employed for lifting-cranes and converter-gear, it comes in well for balancing the top rolls in cogging and roughing mills, and for holding and measuring blooms at the hot-slab shears. It has also been applied with remarkable success for tilting the ingots and slabs in cogging mills, for reversing cylinders, and for testing machines. At the Britannia Works a triple-cylinder hydraulic straightening-machine for heavy work, a hydraulic coupling-jack, and various other hydraulic tools are in daily use.

Hot-Slab Shears and Hydraulic Forging.—Only six years ago it was the custom to hammer steel ingots, and then cut them with a knife to the various weights necessary for making plates. This somewhat slow and clumsy process had the disadvantage that the blooms could not be made of the exact weights required. Consequently there was risk of rejection from being too small, or of waste from being too large. All this has now been done away with by the hot-slab shears and the hydraulic stop-apparatus developed by the late Mr. John Finlayson and by Mr. J. Hartley Wicksteed, Member of Council, and now almost universally adopted. It was a long time before it was clearly proved and generally admitted that cogged steel-ingots would produce as reliable plates as those which had been hammered. To this day there is here and there an ardent champion of hammering as against cogging, and among the South Wales tin-plate makers there are still some who will pay more for tin bars which have been hammered, than for those which have been cogged. In the North-East district however there is no longer any hammering except in the manufacture of forgings, and even here the tendency is to substitute hydraulic forging-presses.

Cogging Mill for Plates and Steel Sections.—Only a short time ago, plates were made at some works from shallow flat ingots passed only through the roughing and finishing rolls of a plate mill. Experience has shown however that, in order to obtain the requisite quality in the finished plate, it is necessary to reduce from a large ingot, which necessitates the use of a separate cogging mill. Plates for ships, boilers, bridges, etc., would not otherwise stand the somewhat rigid tests to which they are now subjected by public authorities, nor could the quality be kept uniformly good. Not only so, but it has been shown to be poor economy to use the plate mill for reducing from the ingot. The addition of a good cogging mill enables a plate mill to double its output, besides improving the quality. A production of 100 tons per shift or 1,000 tons per week is now not an uncommon average performance for a single steel-plate mill, and as much as 1,340 tons have been turned out in a week.

The earlier steel-section mills were not aided by a separate cogging mill. The ingot was put in at one end of the train, and the finished angle or other section brought out at the other; but this required considerable time. Now the cogging is all done elsewhere. Consequently the output of the finishing mill has been largely increased. The further advantage has been gained that the ingots can all be cast of one size, or of a very few sizes, and these very large. And as the blooms can be cut to any weight, the lengths issuing from the finishing mill can be varied, and the waste from crop ends reduced to a minimum. Three-ton ingots for section mills and four-ton for plate mills are now usual sizes.

Steel-Melting Furnaces. — The open-hearth melting-furnaces employed in the North-East district, which produce the bulk of the steel here manufactured, differ but little from the type devised and perfected by the late Sir William Siemens, Past-President, except that there has been a tendency to increase their capacity. A 30-ton furnace is now quite common, while there are some as large as 50 tons; 40 tons capacity is a convenient size. Although for the most part they are acid furnaces, they could easily be altered to basic whenever circumstances might necessitate that change.

Gas Producers.—In the manufacture of gas for melting-furnaces, iron-cased producers of the Wilson or Ingham types, or modifications thereof, have almost entirely superseded those of the original Siemens pattern. In some cases the ashpit is filled with water, and the casing is carried down below the level thereof, so as to form a water seal. All the ashes dropping from the fire-grate fall into this water, and are raked out occasionally from two pockets in the ashpit on opposite sides, through the water seal. It is claimed that this obviates the necessity for stopping for that purpose, and makes the action of the producer practically continuous. The supply of air for combustion is brought into the sealed ashpit by a pipe leading from a steam-jet injector.

Steel Foundries.—No account of the iron and steel industries of the North-East district would be complete which omitted to mention the steel-foundry trade that has sprung up during the last few years. There are six steel foundries in active operation, namely those belonging to Messrs. John Rogerson and Co. at Wolsingham, Messrs. John Spencer and Sons at Newburn, Messrs. Ridley and Co. at Swalwell, the Darlington Forge Co. at Darlington, Messrs. William Shaw and Co. at Middlesbrough, and Messrs. Sutherst and Southorn at Guisborough. The first was established about 1862 by the late Mr. Charles Attwood. It is an extensive establishment, producing steel castings, forgings, machined work, and quick-firing and Nordenfelt guns up to 6 inches calibre. Propeller-blades, dredger-buckets, anchors, stern and rudder posts for ships, crank-shafts, locomotive driving-wheels, shot and shell, are also made there. The Darlington Forge is an important concern engaged on similar but less various work.

At Middlesbrough, the only steel foundry is that carried on by Messrs. William Shaw and Co., Mr. Shaw having been for many years manager at Wolsingham. At this foundry the usual charge consists of 10 per cent. hematite pig-iron, and 90 per cent. steel scrap. The castings contain from 0·16 to 1·5 per cent. of carbon, and withstand a tensile stress of from 26 to 35 tons per square inch. The softer qualities in their unannealed condition will extend 18 per cent., and bend double round a bar 1 inch diameter. Mr. Shaw claims to be able to make castings without blow-holes, and has abandoned annealing except where specified, believing it unnecessary if the metal be of proper composition.

In conclusion I desire to tender my best thanks to the many owners of works, engineers, and others, who have kindly aided me with information, and so facilitated my attempt to lay before you some account of what has been done towards the development of the Cleveland Iron and Steel Industries during the last twenty years.

Discussion.

Sir Lowthian Bell, Bart., Past-President, dissented from the closing words of the paper, which described it as giving merely "some" account of the Cleveland iron and steel industries. It appeared to him to be one of the most complete accounts of what had been done in the district during the last twenty years; and he was sure the meeting would join him in an expression of thanks to Mr. Head for so excellent a paper. In its latest developments the iron trade in the district had had many difficulties to encounter. In the first instance the Bessemer process had put an end to the production of iron rails; and scarcely had the iron works recovered from that blow, by a great demand fortunately arising for iron ship-plates, when steel again presented itself as a formidable opponent to the Cleveland iron trade. It was useless however to question that which nature pointed out to be the proper course. Those seeming misfortunes to the Cleveland iron trade had of course set many minds thinking, in this and other districts, how the new difficulties were to be met. Amongst others there were what might be called artificial difficulties to be encountered. One of these was a fixed idea in the minds of iron makers that there was some peculiarity in particular ores which fitted them for certain purposes better than any other ores; and he remembered that an old and intimate friend of his, the late Mr. James Kitson of Leeds, had to the last retained the belief that there was something in the West Yorkshire iron which specially fitted it for purposes where great strength was required. That cardinal point however in the faith of former years had now been abandoned. It had come to be recognised that iron was the same in all ores; and that if a particular ore was less suitable for certain purposes than other ores, it was because it contained certain impurities. On this subject he remembered talking with the late Mr. Dawson, the managing partner in the Low Moor Iron Works, who was most anxious to ascertain what ingredient it was, to the presence of which Low Moor iron owed its great strength and purity. Thus, instead of investigating what was the cause of good iron being made bad, he went in the opposite direction; and he soon ceased the enquiries which he had been making. The malleable iron trade of this district had indeed had a hard battle to fight. There was no doubt in his own mind that the day would arrive when all the malleable iron known in the arts would be made by what was called the pneumatic process—either the Bessemer or the open-hearth process: because in point of fact nine-tenths of the so-called steel that was now produced was in reality malleable iron; chemically it differed in no way from the Low Moor iron of olden days. Possibly Mr. Windsor Richards, in whose presence he was speaking, did not altogether agree with this opinion.

Another matter connected with the introduction of steel was its alleged greater liability to corrosion (page 242). It should be remembered that its corrosion was at present rather of an irregular character. After some delay the use of steel had now been universally adopted for locomotive boilers on the North Eastern Railway. No doubt it had sometimes been a little disturbing to find that some of the steel locomotive boilers appeared to corrode much more rapidly than iron boilers did in former days. But it was necessary not to lose sight of the circumstance that for one steel boiler which corroded in that rapid way there were a hundred which showed no signs of corrosion. It required only close observation and great patience, he believed, in order to ascertain the cause of the occasional greater liability to corrosion on the part of steel than on the part of iron.

As a foundation for what he believed would continue to be the soundness of the Cleveland iron trade, there was the fact that the district could produce its own ore, and had at its command excellent fuel; and if it were recognised that any inferiority of quality was due to the presence of particular ingredients, he had no doubt that science would enable the product to be freed from those impurities which interfered with its tenacity and durability. Circumstances no doubt, as mentioned in the paper (page 245), had conspired to render the introduction of the so-called basic process less rapid in this district than it had been in others; but the want of progress in this direction arose simply from the circumstance so clearly pointed out by the author. He was delighted that the Institution of Mechanical Engineers had selected Middlesbrough once more as a place of meeting, and that there was so numerous and attentive an audience to listen to the papers announced to be read and discussed.

Mr. E. Windsor Richards, Vice-President, while ready to admit, in agreement with what had been said by Sir Lowthian Bell, that steel might possibly in the future be made as good as iron, considered that at present even the mildest steel was not fit to be compared with the best Yorkshire iron for certain purposes. The reason lay in the fact hinted at by Sir Lowthian Bell, namely that, in order to make steel castings of any use, it was necessary to add metalloids to the metal. Pure iron however had no metalloid in it. The consequence of the addition of any metalloid in steel was that it was made brittle. It did not matter how soft the steel might be; if a piece of it were nicked after it had been cast and rolled, it would break short across under a blow; whereas a piece of good pure iron had to be nicked all the way round, and deeply, before it would break. Then again there was no fibre in steel. Fibre might be obtained by a large addition of sulphur, which however was not a desirable metalloid to put in; but even then the steel was unreliable. He congratulated the Institution upon having received such an able paper, and was sure their best thanks were due to the author for having prepared it for the present meeting.

Mr. Charles Cochrane, Past-President, referring to the question, essentially one of mechanical engineering, which was raised in page 232 of the paper, as to the internal strains in a blast-furnace, was himself unable to agree with the statement that in furnaces made of the ordinary shape the whole weight of the charge rested upon the inverted conical surface of the bosh and upon the hearth, the consequence being that the descending charge became tightly packed at the region where it was in a semi-fused or plastic condition. Taking the diagram, Fig. 3, Plate 41, to represent the vertical section of a cylinder or furnace 23 feet in diameter—which was the diameter given by Mr. Head (page 231) for one of the blast-furnaces he had referred to—the section might be divided into a cone ABC at the bottom, above it an annular figure of the section ACD or BCE, and at the top a double cone CDFE. In such a furnace, assuming that the limiting slope of the materials was 45° and that nothing would rest at a steeper angle, and that the weight of the materials averaged two-thirds of a ton per cubic yard, the weight of the lower cone would be about 39 tons, of the annular mass about 156 tons, and of the top cone about 78 tons. On the limiting slope of the materials nothing would rest; everything would either slide or roll down. Any load placed upon it, small or large, was supported jointly by a pressure perpendicular to its surface and by a thrust parallel thereto; and each of these was again capable of resolution into a horizontal and a vertical force. The horizontal force was transmitted as an outward thrust to the walls of the furnace, and determined the needed strength of the walls in tension. The vertical force, in consequence of the friction produced by the outward thrust against the walls, was conveyed through the walls down to the foundation; in no other way could the materials above the bottom cone be supported. In regard to the bottom cone itself, weighing 39 tons, it was obvious that not one particle of its weight reached the walls of the furnace; it was all supported on the base. Of the annular mass above, which as here drawn was four times the weight of the bottom cone, it was seen that, by the principle of the parallelogram of forces and with the limiting angle of 45°, the proportion reaching the base within the circle of the containing wall would be exactly one half of its total weight of

156 tons, that is it would be 78 tons. Therefore from these two portions of the materials together 78 + 39 = 117 tons was the joint weight reaching the base on which the bottom cone rested. Coming to the double cone at top CDFE, weighing about 78 tons, it would be found, by following the principle of the parallelogram of forces, that not one particle of this weight ever reached the base, but the whole of it was supported by the sides; from the conical surface DCE upwards, not an ounce of the weight reached the floor of the furnace except through the enclosing walls, which of course supported the whole of the weight above. It was like the case of a man climbing down the inside of a chimney, supporting his weight by the pressure of his back and his knees against the opposite walls: till his feet touched the bottom, none of his weight reached there except through the walls of the chimney itself; so was it with regard to the strains supporting the materials of a blast-furnace within itself. This was no mere theory; it admitted of the simplest demonstration, and he had himself tested it with tubes of from 2 inches up to 5·83 inches diameter and of 18 inches height. Into a tube of 5·83 inches diameter he had placed 5 lbs. of oats, occupying a height of about 9 inches, and had ascertained by means of a balance the pressure on the base of the column. Assuming the same limiting angle of 45°, the weight of the bottom cone ACB, Fig. 3, was calculated in this case to be 0·56 lb., and that of the annular mass ACD, BCE to be 2·24 lbs., of which one half was transmitted to the bottom. The total pressure on the bottom would therefore be 0·56 + 1·12 = 1·68 lb. according to this calculation. On slightly raising the external tube or cylinder, so as just to relieve the friction of the oats against the side of the cylinder and to allow a few to escape on to the pan of the balance, the weight obtained on the balance was 1·75 lb., or only 0·07 lb. in excess of the calculated amount. He had repeated the experiment, piling up the oats to different heights in various tubes, and not an ounce more pressure would ever reach the floor than was indicated by similar calculations for each case. Applying the foregoing calculation to a base of 13 feet diameter in a blast-furnace, just above the tuyeres, where according to the theory implied in the paper it might be

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supposed that the greatest pressure would be met with, the conclusion he was led to arrive at was that in a furnace of 25,000 cubic feet capacity, containing 611 tons of materials, the whole weight that could be brought to bear on that base would be not more than $7 \cdot 04 + 14 \cdot 08 = 21 \cdot 12$ tons. Whatever benefit therefore had been thought to result from the supposed removal of pressure from a region which did not and never would possess it, must have been derived from some other cause which he thought must have been overlooked. Upon the statement that an improvement had been observed he did not throw any doubt; but he considered it had not arisen from having relieved the furnace from any pressure below. The contraction of the sides of the furnace had simply taken pressure off the sides themselves, and had also reduced its capacity; but no advantage could have been gained from a circumstance which did not in fact exist, or from the removal of a difficulty which had been supposed to exist but which really did not.

After the reference that had been made (page 237) to the duration of the lining in one of the furnaces at the Ormesby Iron Works, it might be of interest to add some further information upon the question of the mechanical wear and tear on the internal lining of a blast-furnace. The particular furnace (No. 1) referred to as having been nearly eighteen years in blast had been blown out in January 1892, the time having been more precisely seventeen years and ten months. In the upper end or throat of the furnace, which was originally 23 feet diameter, it was extraordinary what an amount of wear had taken place. Bricks 2½ feet thick had been reduced to only 4 inches, as the result of the material sliding off the charging bell and striking against the side of the throat at a depth of about 13½ feet below the top or the level of the filling plates; and also in some measure as the result of the inferior burning of the bricks, which when originally manufactured had been soft-burnt instead of hard-burnt. That wear and tear gave much anxiety for two or three years, during which he had been perpetually on the watch for fear the throat should cave in and compel the furnace to be blown out. Going lower down, at about 50 feet below the top the wear became what might be called natural. With 45° as the limiting angle of natural slope, the pressure outwards was exactly equal to the pressure downwards on each side; and notwithstanding that the furnace walls were inclined slightly outwards towards the bosh, in order to relieve the friction and let the material fall away more freely, there was still a constant wear and tear going on, which amounted to 8 or 12 inches thickness of lining in eighteen years. The character of the wear and tear in a furnace was too often judged by the condition of the furnace after it had been blown out. That was not the way to judge of it, in his opinion; the only way to judge of it was by ascertaining the thickness of the lining, measured from the outside of the furnace to the inside of the lining, when the furnace was in full work, by boring holes through it at different places. There might be scaffoldings occurring in the furnace and moving from one side to the other, causing contraction in cross section; or in consequence of wear the furnace might become enlarged, so as really to be working at a much greater capacity than that to which it was originally built. An illustration of such enlargement and contraction was furnished by the working of No. 1 and No. 2 furnaces at the Ormesby Iron Works (Proceedings 1882, Plates 51 and 52), in which the cone of the lining in the neighbourhood of the top of the bosh had been constructed in the two different ways shown in the diagrams, Figs. 1 and 2, Plate 41. In No. 1 furnace now blown out, Fig. 1, the top of the bosh was 45 ft. above the floor of the hearth; while in No. 2 furnace, which in June 1893 had been seventeen years and two months in blast and was still working, it was 32 ft. above the floor of the hearth, Fig. 2. In both furnaces observations were made at 46 ft. 8 ins. and at 32 ft. above the floor of the hearth. The conical frustum of 14 ft. 8 ins. height between these two levels in each furnace was shown by the full lines in Figs. 1 and 2, as originally built: in No. 1 furnace the diameters at top and bottom of the figure were 28 ft. 8 ins. and 22 ft. 1 in. respectively, with an intermediate diameter of 28 ft. 11 ins. at top of bosh; while in No. 2 they were 26 ft. 6 ins. and 28 ft. respectively. By boring holes through the walls of the furnace on each side, the following remarkable changes were found to have occurred, as shown by the dotted lines in Figs. 1 and 2, taking the average of four or

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five observations made on each furnace during the year 1891. At the upper level of 46 ft. 8 ins., No. 1 furnace had become enlarged from 28 ft. 8 ins. to 30 feet, with an average working diameter during the year of 29 ft. 5 ins.; while in No. 2 furnace the average working diameter had increased from 26 ft. 6 ins. to 27 ft. 9 ins. At the lower level of 32 ft., No. 1 had enlarged from 22 ft. 1 in. to 26 ft. 8 ins., with an average working diameter of 24 ft. 8 ins.; while No. 2 on the contrary had become reduced from 28 ft. to 25 ft. 5 ins. working diameter. These changes showed how a wrongly constructed furnace would adapt itself if it was too large or too small in certain working parts. Coming lower down in the furnace, the greatest amount of wear on the sides was met with at about 27 feet above the hearth, where the bosh was entirely gone, including the backing; and below this point, at about 20 feet height, there had been as much as 4 ft. 8 ins. thickness of brickwork eaten away during the eighteen years, or at the rate of 3 inches per annum. These he thought were important facts in regard to the working of blast-furnaces. As originally built No. 1 furnace had a capacity of 31,793 cubic feet; during its eighteen years of work it rose to a capacity of 37,000 cubic feet, having grown 5,200 cubic feet in that time. With regard to the wear and tear at the bottom of the bosh, it was limited and controlled by the effect of the water tuyeres and the radiation; just above the tuyeres as much as 2½ feet thickness of brickwork had been swept away in three weeks, or at the rate of from 1 inch to 1½ inch per day. It was only recently that he had satisfied himself about this rate of wear; and it was a vital point to know whether the brickwork did go speedily. Where there were all the advantages that were necessary, the way to meet this wear was to enlarge the hearth a little in diameter; then there was not so much of the lining to wear away before the balancing point was reached at which the tuyeres and the radiation would prevent further mischief. With regard to the American practice of forcing the blast-furnaces, it was not the quantity of pig-iron run out, but the quantity of materials passing over the surface of the lining, that formed the real criterion of durability. In one of the American furnaces turning out an enormous output he had calculated that during its life-time of three years 1¼ million tons of material must have passed over the brickwork lining; but in the case of No. 1 furnace at Ormesby more than 2 million tons of material had passed over the brickwork of the furnace before it was finally destroyed, having then become fairly worn out.

Mr. Hammersley Heenan thought there would be a mistake in calculating from experiments with oats in a small tube (page 257) how the materials would be supported in a blast-furnace. Although the friction on the sides of the small tube might hold the oats, yet, if that tube was enlarged, the mass of the oats would increase as the square of the diameter, while the supporting friction round the sides would increase only as the diameter. Therefore if the tube was made large enough, the whole weight would rest on the bottom.

Mr. Druitt Halpin thought there was one point that had been overlooked in regard to this question. As far as he understood the argument, it appeared to be assumed that the angle of repose was constant. That assumption however he thought was hardly justified, because the material to be dealt with in a blast-furnace was of a varying temperature. In fact at the bottom it was liquid, and going upwards there were strata of increasing viscosity: so that, instead of a straight line representing the angle of repose, there would be a curve of some complication, which might greatly change the conditions supposed in the diagram, Fig. 3, Plate 41.

In page 249 of the paper it was stated that the employment of a separate condenser and air-pump, for the use in common of all the engines in a mill, had often been suggested; but that hitherto the plan had not been carried into effect, because of the relatively large quantity of cooling water which was required to maintain a continuous vacuum under intermittent conditions. In a large ironworks which he had lately seen, comprising blast-furnace and rolling-mill and steel works, condensation was being effected not only without water, but, if it might so be said, with less than no water, and not by the old well-known method of the evaporative surface-condenser. The quantity of cooling water was actually increasing during the condensation, and some of it had to be allowed

(Mr. Druitt Halpin.)

to run away to waste. The amount of feed-water necessary for the condensing engines had been reduced, and a separate condensing apparatus driven by an engine of 200 horse-power had been provided, which served for the working of engines developing altogether about 10,000 horse-power. As a matter of fact, only a small quantity of condensing water was used, about enough to condense for ten minutes with the ordinary jet-condensers and air-pumps worked by the 200 horse-power engine. As fast as it became heated by use, the water was then cooled by being pumped up to the top of a tower 24 feet high, and allowed to trickle down over the surface of vertical boards inside the tower, which were arranged in alternate tiers at right angles to one another. At the bottom of the tower was a fan driving a large volume of air in. The result was that a cooling effect was produced in two ways: through the heat that was carried off by the ascending air-current, and through the latent heat that was absorbed by evaporation. By this means the water was so effectually cooled that it could be used over and over again.* Having measured the vacuum with a barometer, he had found that 93 per cent. of a perfect vacuum was obtained in this way. The cooling water was exceedingly good, because, being used over and over again, it became almost absolutely free from air, which was a matter of the greatest advantage in jet-condensers.

Mr. Richard Howson stated that in a series of experiments at the Newport Iron Works it had been proved incontestibly that there was a great relief of pressure in the blast-furnace by shouldering the weight of the charge by means of one or more slightly projecting boshes added in the upper part of the furnace. As far as results had up to the present been obtained, they showed that the furnace so modified had done an average of as much as 40 per cent. more work under the same conditions of blast, stove power, fuel, and ironstone as previously, with a saving of more than one cwt. of coke per ton of pig, producing also a better quality of iron than it ever did before.

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* Zeitschrift des Vereines deutscher Ingenieure, vol. xxxvi, 1892, page 104. Proceedings Institution of Civil Engineers, vol. cviii, 1892, page 479.

Mr. William Hawdon explained that the internal profile of the altered blast-furnace at the Newport Iron Works was now as shown in Fig. 4, Plate 42, the two upper boshes having been added at AA and BB. The furnace was originally 28 feet diameter inside, from the throat down to the ordinary bosh. The uppermost bosh AA was about 22 feet down from the top; and the lower bosh BB was about 20 feet below it, or about 26 feet above the ordinary bosh CC, which latter was much nearer the bottom and rather less steep than was generally the case in a blast-furnace. It had been proved by models that the two upper boshes in the altered furnace really did support a considerable part of the weight of the charge, and thereby left the charge in the lower portion of the furnace in a much more open condition than was usual. What had been done was to make the lower part of the furnace of smaller capacity, and the bottom bosh CC as low down as possible, so as to get the materials on it in a semi-molten condition; and it had been found that in consequence the materials did not scaffold. A scaffold he considered was not formed altogether by the weight of the charge, but was partly due to the semi-plastic condition in which the charge came upon the bosh of an ordinary furnace. The whole weight of the charge did not rest upon the inverted cone of the bottom bosh; but although it was partly sustained by friction against the sides of the furnace, a great deal of the weight came straight down the centre, and it was in order to relieve this that the sides of the furnace were made to taper downwards like an inverted cone, to form the ordinary bosh. In the experiments tried by Mr. Cochrane with oats (page 257), it could readily be understood that in a small tube the oats would stick; but in a vessel 20 feet diameter that would not be the case. It was the same with the materials in a blast-furnace; they did not stick, and their weight brought them down towards the bottom. When the ordinary bosh of the furnace was brought as low down as possible, within 12 or 13 feet of the hearth, as shown at CC in Fig. 4, it was found that the material was melted by the time it reached the bosh, and it could not possibly stick there. The upper boshes A and B were put so high up as to be out of the melting zone of the furnace, and at that height the materials were simply being dried; they were not at all plastic, and

(Mr. William Hawdon.)

therefore they did not stick. Above the uppermost bosh the furnace was enlarged to the top, in order to get increased capacity in which the gases could act on the fresh charges as they were put in. As stated by Mr. Howson, the furnace had made since the alteration about 40 per cent. more iron of good quality, ranging from 2·3 to 2·5 grey iron, that is between No. 2 and No. 3 quality. There was also a considerable reduction in the fuel consumption, and the working was regular.

Sir Frederick Bramwell, Bart., Past-President, did not know how far Mr. Cochrane's experiments with oats in a tube (page 257) were strictly applicable to the materials in a blast-furnace; if the materials in the lower part of the furnace were in a pasty or a semi-fluid condition, he should think it would alter the analogy. It should be remembered that practical experiments on the storing of grain in lofty cylinders or bins, as much as 80 feet high and 12 to 14 feet diameter, were to be seen daily in Liverpool (Proceedings 1891, page 372); and it was clearly demonstrated by experience that there was no greater pressure at the bottom of those bins by any addition to the height of the column of grain stored in them. That is to say, after a certain height had been reached, the bins might be made as much higher as was wished, without obtaining any increased pressure on the bottom.

Mr. William Sisson enquired what had been the original performance of the altered Newport furnace before the alteration described (page 263) had been tried. This information was wanted for enabling an idea to be formed as to what was meant by the increased make of 40 per cent. Had the Newport furnace been performing as well as the Ormesby furnaces to begin with? If so, great force was to be attached to the statement that an improvement of as much as 40 per cent. had been attained by the alteration; but if the previous performance of the Newport furnace had not been equal to the best of the Cleveland district, some deduction would have to be made from the 40 per cent.

With regard to the question of increasing the linear dimensions of the vessels referred to (page 257) containing granular matter, it should be observed that if the diameter were increased the height must also be increased proportionately. It had been remarked (page 261) that if the diameter was increased the state of things would be different; and so it would be if a 6-inch cylinder of 2 feet height were enlarged to 22 feet diameter without any increase of height. But if the height was increased proportionately, the same state of things would still hold good.

As to the performance of the American furnaces, it appeared to him that not only had their more rapid wear to be taken into account, but also the fact that their fuel consumption was so much higher. They were working with ore containing 61 per cent. of metallic iron, whereas the Cleveland ore averaged only 40 per cent. Yet the American furnaces consumed as much as 15 cwts. of coke per ton of iron produced, while the Cleveland consumed only 20 cwts., although the latter had to deal with 50 per cent. more material. So that the great performance of the American furnaces was obtained not only at a great cost of maintenance—which might or might not be expedient, according to the amount of capital outlay on the blast-furnace and its associated plant—but also at the cost of a substantial increase in the fuel consumption per ton of pig-iron made.

The quantity of the feed make-up at the Ormesby Iron Works (page 234) seemed to him to be high in proportion to what engineers were accustomed to in marine engines. About one ton of feed make-up per 24 hours per 1,000 I.H.P. was considered a fair amount in triple-expansion marine machinery, where the steam consumption might be taken at 15 lbs. per I.H.P. per hour; and this would correspond with about two tons per 24 hours in the case of the Ormesby engines, assuming their steam consumption to be about 30 lbs. per I.H.P. per hour; but it was given as nearly sixty tons. Or, to put the comparison in another way, the feed make-up in marine engines was about 1–160th of the total feed, while at Ormesby it was 1–6th, or say 27 times as much. For this he could not see the necessity, unless there was a great deal more waste of steam blowing off from the safety-valves of the blast-furnace boilers, and leakage at glands &c., or steam used in non-condensing engines.

Mr. William H. White, C.B., Member of Council, said it had been his fortune many years ago to have a considerable acquaintance with the best Yorkshire iron, of which Mr. Windsor Richards had spoken in such high terms (page 255). At that time in the Admiralty service for certain portions of ships and of boilers this special quality of iron had always been used. That had been entirely changed, not because there was a word to be said against best Yorkshire iron, but because, thanks to the progress of metallurgy, a material could now be obtained at a much less cost, which had qualities quite sufficient for practical purposes, and which in their experience compared favourably with the high quality of Yorkshire iron. After all, most of those questions, which at one particular moment were receiving special attention, turned mainly upon what a material cost; and the same remark applied he supposed to a good many things which were said in the paper to be still happening in the Cleveland district. Thus the fact had been referred to (page 245) that even in Cleveland the basic process was being applied only to a moderate extent to steel making; and the explanation he presumed was to be found in the circumstance that, importing hematite ore as the steel manufacturers at present could do, they preferred for commercial reasons to continue to make steel from this kind of ore instead of from the Cleveland. In the Admiralty service there had been a continuous endeavour to encourage the basic process of steel-making from native ore. Admiralty officers had done their best to test the matter on the side of its possibilities; and the results of their enquiries were fully known, having already been placed by himself before the Iron and Steel Institute (Journal 1892, part 1, page 32). They had satisfied themselves that by the open-hearth basic process they could get such a material as they could trust. They were not prepared to use basic steel made by the Bessemer process for all purposes in ship work, nor at present to use basic steel made by either process for boiler work; but for ship work they had been prepared for some time past, other things being equal, to use open-hearth basic steel. But other things were found not to be equal: when it came to the test of a contract the basic process had not the relative standing with the acid process that it might be expected to have; in fact acid open-hearth steel could be bought at a cheaper rate in the quantities required than the basic had ever yet been offered at. This might not continue to be the case; but he presumed that, if such circumstances occurred as Mr. Head conceived to be possible (page 245)—namely if from any cause the importation of hematite ore were to be interfered with and the cost of the material made from it were to go up—the development of the basic process for native ores in the Cleveland district might then be looked for.

With regard to certain difficulties arising in the use of steel, he did not altogether agree with the summary given in the paper (page 242). It was the custom, as he knew, to say that mild steel was more difficult to weld than iron. That was so when first the workmen began to gain their experience; but in the dockyards they had now been using mild steel for nearly twenty years for shipbuilding. He well remembered how at first the smiths said that they must be allowed to use iron filling pieces and other special devices for making welds with mild steel; but that condition of things did not last. As the men gained experience, those difficulties of manipulation seemed to disappear. Outside the Admiralty service, when he was upon the Tyne, he had met with exactly the same experience: the older workmen made or felt difficulties at the beginning, but the younger men soon surmounted them. In all his experience, alike in the Admiralty dockyards and in private yards, the result might be summed up by saying that good welding could be done when experience was gained with mild steel; and then its disadvantage or difficulty relatively to iron seemed to disappear.

In regard again to corrosion, while he agreed generally with the statement made in the paper (page 242), yet it did not accord with the Admiralty experience. If steel were treated merely as iron was, that is, if no more trouble were taken at the outset with steel than with iron, there would be a more rapid corrosion of the steel, particularly in the case of ship work. But there were now afloat steel ships eighteen years old, in which the outer bottom steel

(Mr. William H. White, C.B.)

plating was originally half an inch thick and was still in perfect condition, and the ships were doing their work as well as ever. This he thought was a good practical test; but then some lessons had been learned about the employment of steel. It required to be treated initially in rather a different way from iron. The manufacturer's scale was removed from the plates by an acid bath, whereby one of the greatest risks of corrosion that steel had to face was got rid of; and he believed the time might yet come when steel plates would be treated by the makers themselves in a way, by no means expensive, which would remove that source of trouble; it could be done with perfect ease, and, according to his own experience, at little cost. The plates were simply dipped in a bath of dilute acid, as they would be for galvanizing, and were then scrubbed with fresh water; and the manufacturer's scale came away, and any danger of the galvanic action of the scale or oxide upon the body of the plate was thereby removed. Again, the very excellence of the surface of the steel made it necessary to take more trouble with the first coating of paint than would be taken with iron. It was found desirable to look after steel ships when new rather more carefully than would be the case with iron ships. Naturally in the government service more pains could be taken in the maintenance of ships than was possible in the mercantile marine; and it was a matter of common knowledge that in some parts of steel merchant steamers serious corrosion had occurred in practice. But looking merely at the possibilities of the two materials, iron and steel, if proper care were bestowed on the treatment and on the protection of the steel, there was no doubt whatever in his mind that corrosion need not be a serious danger in any sense.

In referring to the fracture of steel and the fracture of iron (page 255), steel had been spoken of by Mr. Windsor Richards as brittle, which he thought was not a fair description, although it was quite true that a bar of steel could be broken in a way in which a bar of Yorkshire iron could not. But another experiment could be referred to, which might have been seen at the Naval Exhibition, where a charge of gun-cotton had been detonated in the immediate neighbourhood of a plate of steel, and again in the immediate neighbourhood of a plate of iron; the iron plate had been shattered simply like earthenware, while the steel plate had merely become dished. Taking the Admiralty experience as a whole — and unfortunately they had had a somewhat large experience of the behaviour of steel under circumstances of grounding, collision, and shocks, of the kind which occurred in practice—he could truly say that no iron which he had ever seen or heard of could have behaved as well as steel had done. The users of steel were indeed under the greatest obligations to steel-makers for having given them such a material; and he had no doubt that a still further improved material would yet be produced. Taking things as they now were, he considered that engineers and shipbuilders had gained in every way, and not least in cost, by the substitution of steel for iron; and he only hoped that, when the Institution of Mechanical Engineers met again in Middlesbrough, and Mr. Head gave another chapter of its remarkable history, they would learn that the native ores of the district were being made into steel of even better quality than that in use at the present time.

Mr. J. Hartley Wicksteed, Member of Council, wished to express his concurrence in the author's remark (page 242) that iron was still preferred for some uses, especially by country smiths, with whom it was not a question of price, for they filled their racks with the best Yorkshire iron, for which they had to pay not less than 17*s.* or 18*s.* per cwt. This was three times as much as they had to pay for steel; yet, even where they were not working to specifications or under inspection, they kept filling their racks every quarter with the best Yorkshire iron at these higher prices. One reason he believed was that best Yorkshire iron was always the same in quality, but steel was not. Bars of steel might vary much in their qualities; but a bar of the best Yorkshire iron, no matter of what shape, whether round or square, could be bought of any size which best answered the purpose, and could be fully relied upon for that purpose. If it were wished to weld another bar or a collar on it, a good weld could be obtained. If it were wished to make a jaw for the chuck of a lathe, the bar could be hammered into that form, and afterwards case-

(Mr. J. Hartley Wicksteed.)

hardened; and it would take case-hardening deeply and without a crack. If it were wished to make a shaft to run in a cast-iron bearing, it could be made from that iron, and it would run with a reasonable pressure without chafing and without seizing. It did not seem to have been noticed, in any of the comparisons made between steel and iron, that there was a great difference between them in respect of the power which was possessed by good iron to resist abrasion. If a mild steel bar, of a quality that would weld freely and case-harden freely, was put to work in a cast-iron bearing, it was liable to seize if it rubbed against the bearing with even a light pressure when running at all dry; and when it began to seize, it did not score like an iron shaft, but rolled up almost like a snow-ball rolling in snow, gathering as it rolled. The result was very destructive, because as soon as it began to roll up it tightened the bar in the hole; it heated and expanded and soon fastened itself, and the two pieces were so closely stuck together that they could only be cut apart. No doubt many engineers had had experience of a shaft seizing fast, and knew what a work it was to get it apart. He himself had had experience of a large steel screw just wound gently by hand into a long cast-iron nut, without the force of any leverage or long spanner; and yet during the rubbing of the two surfaces together the screw seized, and every effort to loosen it made it faster, so that the nut had to be cut in two lengthways on the planing machine; and when it had been so cut in two and the halves knocked apart, the one half was found to be completely stuck fast to the steel screw. From this experience he dared not put a mild steel bar to run in a cast-iron bearing. It might be said that the two surfaces should not come in contact, but that there should be a film of oil between them. So there should in working; but supposing a machine had to stop for a week or a month, possibly one or two of the first revolutions would be without lubrication, and the mild steel was so sensitive that it might take hold at once, before it had taken up the oil. If the operations in an engineering shop were conducted on a sufficiently large scale to make it worth while to order a certain number of sizes of mild weldable steel that would case-harden, and certain other sizes of good hard steel that was not wanted for welding or case-hardening but would run well in a cast-iron hole, the difficulty might be overcome; and perhaps this was what ought to be done: though even then the soft steel shaft that had a collar welded on and was not case-hardened would require a brass bush to run in, so as to prevent it from being in danger of seizing. At present, on the principle of following the lines of least resistance and conducting business in the way that best suited their workmen and their customers, country smiths did continue to fill their racks with the best Yorkshire iron, notwithstanding its higher price.

Mr. William Shaw said he had found that on welding a piece of mild steel, low in carbon and containing about 0·4 per cent. of manganese, and then breaking it through the weld, the manganese was almost gone at that part. Having a stronger affinity for oxygen than carbon had, the manganese abandoned the iron before the carbon did; but the instant the carbon began to be touched by the oxygen, the chain of crystallization became distorted, and the metal became what was called red-short at the weld, just where the manganese had gone from. Just beyond each end of the weld it would be found that the metal remained tough; but if mild steel not containing any manganese were welded, it would be found that each end of the weld was as red-short as the middle. This seemed to him to prove that the use of too much manganese in steel plates would create rust more quickly than a smaller quantity, on account of the manganese having a stronger affinity for oxygen than for the iron. Although he believed the opinion was sometimes held that mild steel would not roll unless it contained a certain small percentage of manganese, yet he maintained that the day would come when this material would be made as tough as any Low Moor iron.

Mr. John A. F. Aspinall, Member of Council, was somewhat surprised at such great stress having been laid by Mr. Wicksteed upon the use of Yorkshire iron for so many purposes (page 269). For locomotive work steel was now being used almost entirely. No doubt a better result was obtained with case-hardened wrought-iron than

(Mr. John A. F. Aspinall.)

with some of the hardened steel; but so long as the steel was of a mild character there was no difficulty whatever in case-hardening it, and he was in the habit of making all the wearing parts in locomotives of steel thoroughly well case-hardened. When basic steel was used, it case-hardened exceedingly well. For boilers nothing but steel had been used for some years; and latterly he had made a number of boilers of basic steel, with a view of seeing whether it suited the purpose or not. A certain number of crank-axles had also been made of basic steel; they had run a considerable mileage already, and there seemed no reason to think that they would not do quite as well as those of steel made by the acid process. Of steel fire-boxes however his experience had not been that they could be successful for locomotive work; and in regard to the locomotive fire-boxes there was one point which was worth mentioning in connection with Mr. Richards' remark (page 255) that if steel was nicked it broke easily. A few years ago, when the price of copper had gone up with a bound, it became necessary to see what could be used instead of copper for the stays between the outer and the inner fire-box. Having received some beautiful samples of basic steel, he thought he could not do better than make a number of stays of that material; for the elongation and the reduction of area were both so good that it looked like a material which would do exceedingly well for the purpose. Unfortunately however it turned out that the screwing of the stays caused them to break easily after they had been put in; and every steel stay that had been put in had had to be taken out. The same had been the case, he had since learned, on other railways in England and also on one in Belgium. It had therefore been necessary reluctantly to go back to copper.

With regard to the pressure of the column of materials in a blast-furnace, it occurred to him that there might be some parallel between the descent of the materials in a blast-furnace and of the grain stored in large and deep bins at some of the principal ports. At Fleetwood there was a large grain warehouse, built upon the American plan with a number of vertical bins of 68 feet height, each bin being about 11 feet square. At one time there had been great difficulty on account of the way in which the grain flowed down the bins and out of the orifice at the bottom. It should be borne in mind that in taking grain out of a ship the good material without any chaff or rubbish all came out first, and therefore fell to the bottom of the bin in which it was deposited by the elevator; the inferior material came out last, and therefore lay in the top of the bin. The grain as a rule was sold by the merchant after a sample had been taken at the bottom by the purchaser, who, as the good material came out first, saw nothing of the inferior material at the top. That had caused so much dissatisfaction that the grain elevator and bins had ceased to be used for a time. One of the staff of the Lancashire and Yorkshire Railway however had devised the arrangement known as Sprague's mixer (Proceedings 1891, page 377), which consisted simply of a vertical wooden pipe or spout running down one side from top to bottom of the bin, divided all the way down by a central partition, and having openings through its sides every six or eight feet down. The result was that, as the grain lay naturally at an angle of 30° to the horizontal, and the weight of the grain, except just at the very bottom, was all supported upon the sides of the bin and not upon the bottom, when the bottom of the spout was opened it began to descend equally from all heights in the bin, flowing down through the spout to the bottom so as to give a perfectly fair sample of material from the bottom to the top of the bin. The completeness of the mixing was admirably shown by making a model bin of glass and putting in it a series of layers of different coloured grains. It was then seen that, while there were separate layers of grain from top to bottom of the bin, the mixed sample issuing from the bottom of the spout was composed of every colour in the whole bin. In that way what might be called the commercial difficulty had been got over, and the grain elevator and storage bins had been in use ever since. The fact that the downward pressure of the grain in the bins was taken up entirely by the sides of the bin, except the pressure which was due to the bottom cone, might have some bearing upon the descent of the materials in the blast-furnace; but the materials in a blast-furnace, not being uniform in size like sand or grain, might not obey the same laws. Exactly the same principle could be illustrated perfectly

(Mr. John A. F. Aspinall.)

with sand: if a vertical pipe of say 2 inches diameter was filled with sand, having its bottom end closed simply with a piece of tissue paper held lightly in its place by an india-rubber band, then, however great the height of the pipe, the tissue paper would not burst; and if into the upper end of the pipe a plug rather smaller in diameter than the pipe was inserted, and was hammered by a blacksmith, no force of blow would suffice to break the piece of tissue paper at the bottom; although, as soon as the paper was removed, the sand would all run out of the pipe freely.

Sir Lowthian Bell, Bart., accepted gladly the interesting explanations from Mr. Cochrane and Mr. Aspinall with regard to the behaviour of grain stored in bins; there could be no doubt on the subject, because they had each tried it. But he demurred to the conclusions that had been drawn with regard to the blast-furnace; and he wished to call the attention of blast-furnace managers to one or two parts of their own apparatus which he thought would go far to prove that the retention of materials in the blast-furnace did not always obtain in accordance with the principle of the composition and resolution of forces, on which Mr. Cochrane's view (page 256) was based. His own firm he believed had been the first in the North of England, and probably in the country, who had adopted the plan of receiving the coke in bunkers. These, as was well known, were not even circular in plan, but were long parallelograms, with sloping sides conducting the coke to a small aperture of perhaps 2½ feet square at the bottom; and no difficulty at all had ever been found from the coke blocking the aperture. Again the cylindrical kilns in which the ironstone was calcined were made with an upright cone in the bottom for distributing the ironstone to the bottom doors round the wall of the kiln; and as soon as any door was opened, the ironstone by its own weight slid down the slope of the cone, and was received in the charging wagon beneath. It might be said that this illustration was not quite analogous to the blast-furnace; but he well remembered that in olden times there had always been a small crane attached to every blast-furnace, the object of which was to carry a large heavy shovel or rake; and in blowing a furnace in, instead of going about it in the simple way in which it was now done by turning the blast on from the commencement, a process was adopted called scaffolding the furnace. There was an idea that the materials, after having been heated through their whole mass, were apt to accumulate on the side of the furnace. Probably they did; and in order to obviate this, the furnace keeper before turning on the blast took the large heavy shovel or rake, and brought out at the bottom a portion of the contents of the furnace. Now if there had been any such retention of the materials in the furnace as had been spoken of, the keeper would scarcely have been able to take out any quantity of material in that way. The material kept falling down inside the furnace as it was removed from the bottom. In view of these facts he hesitated to believe that there was no pressure at all exerted on the floor of the furnace by the materials in the upper regions. In his opinion they all came down; and when the furnace was in blast they came down more rapidly, because the fused matter practically acted as a lubricant of the material during its descent.

Mr. Head said he must take the responsibility for the wording of the paragraph (page 232) respecting Messrs. Hawdon and Howson's new plan for building the interior of a blast-furnace. Mr. Howson had been kind enough to hand him a written account of the improvements they had carried out, from which the paragraph had been abridged; and he should be happy to amend it in such a way as they might approve for conveying the sense of their views.* As to what happened in the interior of a blast-furnace, and how the materials came down from the top to the bottom, the materials themselves could be seen when they were put in at the top, and the next thing that was known in the course of their

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* The exact words made use of in the original memorandum received from Mr. Howson were:—"The ordinary lines, however much they may have been varied from time to time, have always this defect, that the whole weight of the charge rests upon the boshes and the hearth, the consequence of which is that the charge gets packed too tightly, and a furnace often gets 'gobbed' by mere pressure." This is practically the same as what is said in page 232 of the paper.

(Mr. Head.)

descent was whatever could be observed through the peep-holes of the tuyeres and at the slag notches and the tapping hole; but what happened in between could not actually be seen, and was left largely to the imagination. It was considered by Mr. Cochrane that something could be learnt from the behaviour of materials like oats passing down through a tube or cylinder resembling a blast-furnace; but other speakers seemed to think that any such inference was to a large extent invalidated by the fact that the materials became viscous even before they reached the zone of fusion. However that might be, he himself thought something might be learnt from the ordinary sand-glass, in which it was necessary, in order that the sand might continue steadily flowing down from the top part of the glass into the bottom, that the sand should be perfectly dry and that the glass should be of a tapering shape; otherwise the sand would not flow steadily from beginning to end. If pressure were to be put on the top of the sand, he had little doubt that it would stop the flow altogether. The action seemed to depend both on the dryness and purity of the sand, and also on its being perfectly loose; if these conditions were complied with, it would then flow down evenly from beginning to end. But if the sand, instead of being perfectly dry, were damp, it would not flow at all. This showed how the condition of the material, whether perfectly dry or in the least degree sticky or viscous, altered the circumstances altogether; as also probably did any pressure put upon the top. He understood that Messrs. Hawdon and Howson—recognising that the materials lower down in the blast-furnace were not in a perfectly dry condition, but viscous, and that there was considerable pressure on the top, and that the passage from the top to the bottom was attended with considerable difficulty — aimed at relieving that difficulty by taking off at all events some of the pressure; and also by ensuring that, if there were any scaffolding or any side wedging, it should occur at the top of the furnace, where the material was dry. Lower down, where the material was in such a pasty or viscous condition that the blast could not readily get through, the object was to relieve the pressure. The principle seemed reasonable and likely to succeed; but after all, if they were able to state that it did succeed and had succeeded—that the furnace now worked better under precisely similar conditions and did more work in a given time than before the alteration—such an argument he thought was hard to controvert.

The President was sure the members would all agree with him in tendering to Mr. Head a hearty vote of thanks for his elaborate and exhaustive paper, parts of which had been so thoroughly discussed.

ON THE MIDDLESBROUGH SALT INDUSTRY.

By Mr. RICHARD GRIGG, of Middlesbrough.
Communicated through Mr. E. Windsor Richards, Vice-President.

Although the Middlesbrough Salt Industry has not previously formed the subject of a paper to the Institution of Mechanical Engineers, it has been ably and exhaustively treated in papers read before other societies, notably by Sir Lowthian Bell before the Institution of Civil Engineers in 1887 (vol. 90, page 131); by Mr. Hugh Bell before the Cleveland Institution of Engineers in April 1883 (page 106); and by Mr. T. W. Stuart before the Society of Chemical Industry in 1888 (vol. 7, page 660). By these writers the matter has been dealt with in the masterly and comprehensive manner which arises from intimate practical knowledge; and, except in one particular, little has been left for others to say. In the one respect excepted, an important development has taken place since the date of the two first named papers, namely in regard to the method of boring, and to the treatment of the wells put down for raising the brine, from which salt is obtained at Middlesbrough. To this branch of the subject Mr. Stuart alone has referred.

Occurrence of Salt Deposits.—As a preliminary to the description of these methods it may be interesting to consider briefly—the conditions under which salt deposits occur; the probable manner of their formation; and the various ways in which they are worked.

Rock salt is generally pink in colour, and more or less impure from admixture with marls; but it is found in almost every colour, pink, brown, green, blue, and grey, while it is sometimes so perfectly transparent that it is possible to read small print through a piece six inches thick. Its deposits are enormous in quantity, and are scattered nearly all over the world. As regards its position in the earth's crust, it is found both at the surface and below it. At Speerenberg in Prussia it lies 4,000 feet deep, while at Arbonne in Savoy it is perched at the snow-line 7,200 feet above sea level. At Cardonne in Spain a mountain of salt rises to a height of nearly 500 feet, while its depth at the base has never been proved. To the north of India lies a great surface salt formation, some 2,000 miles square, which stretches away to the north-west in hill ranges of salt. In the British Isles salt is found in Cheshire, in Worcestershire, at Middlesbrough, at Fleetwood, and at Carrickfergus. It lies below the surface at depths varying from 120 feet in Cheshire to 1,600 feet at Middlesbrough, where the thickness of the bed varies from a mere film up to 119 feet. As showing the abundance of the mineral, it may be mentioned that in the Carpathian mountains a bed is known to exceed 1,200 feet in thickness. A curious calculation has been made as to the quantity of rock salt known to exist, which is estimated to amount to nearly 500 cubic miles, roughly divided as follows:—India and the East, 30 cubic miles; Carpathian mountains, 416; Great Britain, 3; other deposits, 41 cubic miles. After all however the great repository of salt is the sea, in which it is held in a solution averaging about 2·7 per cent. in strength; and it has been estimated that the quantity is equal to over 58,000 cubic miles.

Origin.—About the origin of rock salt there appears to be a good deal of doubt, although the commonly accepted opinion is that it is a sedimentary rock of aqueous origin and formed from the sea. According to Sir Roderick Murchison, distinguished geologists have arrived independently at the conclusion that the great Indian salt deposits are due to eruptive agencies; while Dr. MacCullock gives reasons for his belief that no salt deposits could ever have been produced from the sea, but that they are special and original deposits. In support of the theory of igneous origin, it is pointed out that salt is found in the eruptions of Vesuvius, and that in 1822 so much salt was discharged from this volcano that the peasants quarried it for use; and the analyses of the salt discharged in the various eruptions have been 62·9 per cent. in 1822, 94·3 in 1855, and 46·16 per cent. in 1856.

The balance of probability however appears to point strongly to aqueous origin. It is clear that rain falling upon the earth would absorb its most soluble mineral wherever it came in contact with it, carrying it always to the sea. This process, together with a gradual sinking of parts of the earth's surface, and a consequent long continued inflow from the sea over large and shallow areas where rapid evaporation was in progress, would readily account for such deposits as those at Middlesbrough, where the bed, so far as proved, covers an area of about twenty square miles, and dips from the north west to the south east, the bottom indicating the shape of a huge saucer, and the top nearly flat. Its deposit appears to have begun upon a formation of hard white stone, above which the salt marl, containing an increasing proportion of salt, shades off upwards into nearly pure salt in a thickness of about 20 feet. The bed varies in thickness from a few feet to a maximum of 119 feet, above which the proportion of salt in the marl decreases until the salt is nearly lost in the 20 feet immediately beneath the overlying white stone. This upper layer of the bed is locally known by the name of the rotten marls, and constitutes a grave trouble to the salt industry of Middlesbrough, as will shortly appear.

It is probable that the earliest use of salt by primitive man occurred when he first learned to use a cooking pot, for with boiled meat or cereals salt would be required; whereas raw meat is rich in salt, and fruit also contains it. Green food however contains very little; and as herbivorous animals have consequently an instinctive longing for salt, they probably attracted man's attention to the mineral through their eagerness in licking it wherever found. It may therefore be presumed that the earliest salt workings occurred on a small scale, where surface rock-salt was found, and at the edges of brine springs and salt marshes. Perhaps the most remarkable salt workings of which there is any knowledge are those in the Wieliczka mine in Hungary. It is the largest in the world, and has now been in work 642 years, since 1251. Its high roads and galleries extend upwards of 50 miles, and are 900 feet underground; it has houses, and villages with chapels, and a population of whom many are said never to have reached the surface. The earliest salt workings in England are believed to have been at Hayling Island near Portsmouth; and it is probable that the Romans worked salt at Droitwich and at Northwich, although these names themselves indicate Saxon origin.

Discovery at Middlesbrough.—Like so many discoveries, knowledge of the existence of the Middlesbrough salt bed came about by means of operations undertaken with quite another object. In 1859–62 Messrs. Bolckow, Vaughan and Co., having bored to a depth of 1,200 feet on the south bank of the Tees in search of water, discovered a bed of rock salt 100 feet thick. Shortly afterwards they endeavoured to sink a shaft, with a view to working the mineral as a rock-salt mine. The influx of water however proved to be so serious that after heavy expenditure the attempt was abandoned. In 1874 Messrs. Bell Brothers sank a bore-hole at Clarence, on the north side of the river, and found the salt at 1,127 feet. There the matter rested until 1881, when Sir Lowthian Bell's brother, Mr. Thomas Bell, proposed a method of winning the salt by using one and the same well for sending water down to the salt-bed, and for pumping up the saturated solution, the fresh water going down the annular space between the larger external tube which formed the lining of the well, and the smaller central tube through which the brine was pumped up. Although Mr. Bell was not aware of the fact at the time of proposing this method, it was then already in operation in France; and after a visit to the French works Messrs. Bell sank a well of suitable size, constructed evaporating apparatus, and in 1882 began making salt. To Messrs. Bell Brothers therefore belongs the honour of having been the pioneers of this important industry.

In 1885 the Newcastle Chemical Co. and the Haverton Hill Salt Co. erected works, the former for the purpose of supplying their chemical works on the Tyne with salt, and the latter for general manufacture. The Haverton Hill Salt Co. were the first to make fine salt for domestic use, and to demonstrate that salt of a quality equal to any could be made at Middlesbrough. Messrs. Tennant and Partners, Messrs. Bolckow, Vaughan and Co., the Middlesbrough Owners, the Greatham Salt Co., and the Tees Salt Co., afterwards erected important works; and the production of salt steadily increased from 3,132 tons in 1882 to 231,060 tons in 1892.

Extent of Deposit.—The bed of rock salt, so far as now proved, extends over an area of about five miles long from west to east by four miles wide from north to south, or about twenty square miles, as indicated in the plan, Fig. 1, Plate 43, which gives the position of existing bore-holes. Each square mile is estimated to contain 100,000,000 tons of salt; and although, by any method which now appears likely to be adopted, a proportion probably not exceeding 25 per cent. of the whole can ever be brought to the surface, yet the figures are so large that the question of possible exhaustion of supply need not be taken into account. The most northerly bore-hole is near Greatham, where the bed of salt was found at the depth of 889 feet and is 57 feet thick; the most southerly is at North Ormesby, where it was found at 1,340 feet, and is 79 feet thick; the most easterly at Lackenby, the bed being met with at 1,685 feet and 119 feet thick; and the most westerly at Sandfield, Haverton Hill, where the bed occurs at the depth of 797 feet and is 80 feet thick. The thickness of the bed varies considerably, but the average may be taken at 80 to 90 feet. Including these four bore-holes, the following are the depth and thickness of bed in six borings:—

	Depth to Rock Salt.	Thickness of Main bed of Salt.	
Greatham Salt Co., Greatham .	889 feet.	57 feet.	Most northerly.
Newcastle Chemical Co. . .	1091 ,,	112 ,,	
Bell Brothers, Clarence . . .	1127 ,,	65 ,,	
Haverton Hill Co., Sandfield . .	797 ,,	80 ,,	Most westerly.
Middlesbrough Owners, North Ormesby . . .	1340 ,,	79 ,,	Most southerly.
Lackenby	1685 ,,	119 ,,	Most easterly.

Failure to find salt has occurred in the five following instances, which are marked with a dotted circle in Fig. 1 :—

	Depth bored.	
1. Seaton Carew	1410 feet.	Most northerly.
2. Haverton Hill Co., Sweethills	1000 „	
3. Haverton Hill, near Vicarage	unknown.	
4. Newcastle Chemical Co.	1190 feet.	
5. Whitehouse Wood, Norton	1079 „	Most westerly.

It would seem from Nos. 1, 3, and 4, that the limit of the bed to the north and west and south-west has been defined; while to the south and south-east the increase in depth raises the question of larger cost in boring, tubing, and repairing.

Analysis.—It is difficult to give an average analysis of the bed, owing to difference in proportion of marl mixed with the salt. Samples are obtained showing as high as 98 per cent. of sodium chloride, and as low as 45 per cent.

Brine.—The British production of salt amounts to about 2,000,000 tons per annum, of which 90 per cent. is white salt made from brine. The balance of 10 per cent. is mined chiefly in Cheshire as rock salt; it is of dark red colour, and is suitable only for purposes where a high degree of purity is not essential. All the salt made near Middlesbrough is made from brine by evaporation. Fully saturated brine contains 26½ per cent. of salt; a fair working strength may be roughly taken at 25 per cent.

The problem has been, and continues to be, how to get good brine at a low cost. It is obvious that the presence of a navigable river—the Tees—and the near neighbourhood of coal, are important factors in the successful production of a cheap substance such as salt, inasmuch as more than half of the output is for export, and about half a ton of coal is consumed in the evaporation of brine for the production of each ton of salt. Two other important factors are found in an abundant and cheap supply of good brine, and in sufficient imports to provide cheap tonnage for export. These latter conditions favour Cheshire and Liverpool; and the struggle between the two salt-making districts will lie in the balance of advantage between cheap coal with ready shipment on the one side, and cheap brine with low freights on the other.

In Cheshire the brine is formed by surface water finding access to the rock salt, quickly becoming fully saturated, and then flowing for long distances through crevices or "runs" to the point where it is pumped up. Brine so formed is called "natural brine," and has the enormous advantage of being so abundant that it can be raised at the lowest possible cost by means of large and powerful pumps. As its saturation takes place far away from the pumping station, no disturbance of foundations occurs at the latter through abstraction of the mineral beneath: although much-tried farmers, miles away, find their fields subsiding, until small lakes, having steep and broken sides, are formed. Meanwhile at the pumping station the brine is abundant, strong, cheap, and pure; for in its long and gradual course underground, insoluble particles held in suspension become precipitated. The Cheshire salt industry therefore enjoys the advantage of an ideal position, so far as getting the brine is concerned; and when the salt produced has been conveyed some thirty miles by canal, it commands the tonnage of Liverpool for its export. The disadvantage lies of course in the thirty miles of canal, which is navigated by means of steam craft carrying about 250 tons, each of which tows a string of smaller barges. These enter any dock in which the ship requiring the salt is lying; and they are admirably fitted for rapidly putting their cargoes on board.

Boring of Wells.—At Middlesbrough, as already stated, brine is obtained entirely by boring deep wells. Up to 1886 with two exceptions these were all bored by the Cumberland Diamond Boring Co. (Mr. John Vivian), using the diamond boring process, which is familiar to engineers. A number of black diamonds are fixed with their cutting edges projecting from the end of a short tube, called a crown, which is screwed on the bottom of a core-tube about 18 feet long, and varying in diameter according to the size of the well to be bored. The whole is rotated by hollow rods, through which a pressure of water is maintained. By this means a solid core is obtained, and the process is therefore valuable for prospecting; but the large sums charged for the wells bored in this way, together with the cost and slowness of repairing them, were threatening to destroy the salt industry at Middlesbrough altogether, when the Newcastle Chemical Co. and Messrs. Tennant and Partners obtained information which led to the introduction of the method of drilling practised in the American oil regions, where a large number of wells have been put down, and valuable experience obtained. The success of this method was immediate and complete; wells 1,000 feet deep were sunk in three weeks, instead of as many months, with a corresponding reduction in cost. It completely superseded the diamond boring, and was found so much more efficient for repairing holes, as well as for the original drilling, that not one of the fifty-five wells now in operation at Middlesbrough is without its derrick and American apparatus.

Free-falling Tools.—Drilling is effected by the use of free-falling tools, suspended by a cable. The weight of the tools being about 18 cwts. and the height of fall about 4 feet, blows are given of sufficient force to pierce the hardest rock. The face of the chisel being blunt, the drillings are pounded to powder, and mixed with the water in the hole. After drilling from three to five feet depth, the tools are rapidly withdrawn; and a sand-pump attached to a separate rope is let down, in order to remove the detritus, after which the tools are again used.

Derrick.—The "rig," as it is called in America, bears evidence of having been developed in a country where wood is plentiful; and its rough and ready character often excites the surprise and disapproval of English engineers. But "handsome is that handsome does;" and respect for the rig grows with knowledge of what can be effected by its use in skilful hands. As shown in Figs. 2 and 3, Plate 44, it consists of a derrick 74 feet high, 20 feet square at the base, and 3 feet at the top, surmounted by a crown pulley P, over which passes the drilling cable C or tubing rope, and a snatch-block S for the sand-pump line. A bull wheel and drum D, driven by an endless rope which is rapidly thrown on or off as required, takes the coil of drilling cable C for lifting or lowering tools or tubes. A walking beam B, attached at one end to a crank N, gives the necessary motion to the drilling tools and afterwards to the pump rods. The crank has a throw of 2 feet, giving a stroke of 4 feet to the end of the beam, to which the drilling cable is attached by means of the adjustable screw T; each revolution of the crank thus produces one blow of the drilling tools. The reel R carrying the sand-pump line is worked by a friction pulley F. The whole work is done by two men. The driller standing by his tools has within reach the "telegraph line" E for controlling the engine; the reversing line L attached to the link-motion on the engine; the sand-reel lever V controlling the sand-pump line; and the lever K of the brake on the bull wheel D, which controls the drilling cable and tools.

Drilling Tools.—The tools used are shown in Figs. 4 to 9, Plate 45. They consist of a chisel or "bit" B, stem A 32 feet long, jars J, sinker bar K 10 feet long, and rope socket S. These are called a "string of tools," and are altogether about 50 feet long. They are connected by taper screw-joints, one of which is shown to a larger scale in Fig. 8. This joint gives great strength; a few turns bring it home, and an arrangement of levers screws it up so tightly that it does not often unscrew in use, notwithstanding the vibration to which incessant blows subject the tools. The jars J, Fig. 6, are a pair of links having a vertical play of nine inches; they are for the purpose of freeing the tools if jammed or fastened in any way, by enabling the driller to give a succession of upward blows which loosen the tools, no matter how firmly they may be held. The temper screw T, Fig. 5, is an ingenious contrivance for attaching the cable C to the walking beam, and enables the driller to slacken or tighten the cable, and to cause the tools to revolve when drilling. In Fig. 9 is shown a section of the sand pump. What can be effected by these appliances in the hands of a highly skilled driller is little short of the marvellous. Holes have been drilled nearly a mile in depth, perfectly straight and perfectly round. In Austria indeed a hole is reported to have been drilled to a depth of over 6,000 feet; but the deepest American hole, at Pittsburg, is 4,618 feet.

Accidents.—The driller's only knowledge of the tools while in the bore-hole is through the cable, which his hand never leaves while drilling. Extraordinary complications sometimes arise; a faulty joint may unscrew, or a tool break, the upper end of which may be driven quite aside from the line of the hole. In the effort to recover it, other tools may be lost, until perhaps a ton of iron blocks the well. On all this a "run in" may occur, burying the whole possibly a hundred feet deep, and at a thousand feet or more below the surface. With patient and wonderful skill the hole is cleaned out, tool after tool withdrawn, and the cause of the mischief straightened up and got out. Or the hole may collapse, burying the tools, and "sticking" the jars. Then the cable is cut at the lowest accessible point; the hole is lined with tubes, which follow the tools down; the buried tools are got hold of, and by the action of jars are drawn out inch by inch. Sometimes, though rarely, holes have to be abandoned as the result of such accidents.

Sinking and Lining of Middlesbrough Wells.—The diameter of the Middlesbrough wells is eight inches. After construction of the rig, the first process is to drive down 10-inch tubes, furnished with a strong shoe, through the surface clay, sand, gravel, &c., to a depth of from 80 to 130 feet, till the sandstone is reached: for which purpose the rig is temporarily transformed into a clumsy-looking but efficient pile-driver. After this the drilling begins. Thicknesses of from 300 to 700 feet of water-bearing red-sandstone are passed through, then red marl down to the white stone overlying the salt, then rotten marl, and then the salt-bed; the drilling stops at the bottom of the salt. The 8-inch hole is then lined, either throughout from top to bottom, or else only through the bottom 200 feet, which is the region of falls of marl. For this bottom portion tubes are used of half-inch thickness and $5\frac{1}{2}$ inches bore. If the hole is lined higher up, the tubes are $\frac{1}{4}$ inch thick and $6\frac{1}{2}$ inches bore; at the couplings they are then $7\frac{1}{2}$ inches diameter outside. In Fig. 10, Plate 46, is shown a section of a brine well at Port Clarence. The tubes are perforated at A, to permit ingress of water from the sandstone; and again at B at the top of the salt bed, to let this water flow over the rock salt. They are also perforated at C at the bottom of the bed, to permit ingress of brine to the pump tubes D. The latter are $\frac{1}{4}$ inch thick and 4 inches bore from the surface down to 250 feet depth, as far as the pump barrel E; and thence $3\frac{1}{2}$ inches bore below, down to the bottom, where they are perforated at F through a length of 4 feet to admit the brine. The pump is $3\frac{3}{4}$ inches bore with 4 feet stroke, and is connected by iron rods to the walking beam, and provided with a stuffing-box and brine outlet at surface.

Pumping of Brine.—As soon as the well is bored, the pump tubes in place, and the pump rods attached, the small space occupied by the well in the salt bed will be filled with fully saturated brine; and the pump being started at the normal speed of twelve to fourteen strokes per minute, the first discharge will be water, until the brine, passing up the suction pipe, appears in a muddy stream. It quickly clears, and as quickly becomes weak, through the exhaustion of the contents of the cavity which is as yet small. Water is found in the sandstone within twenty feet of the surface, and, standing in the annular space, balances the column of brine so far as the difference in their specific gravity permits. A column of water 1,200 feet supports one of brine having a height of nearly 1,000 feet; the pump therefore has really to lift the brine only about 200 feet. A new well, if working properly, increases daily in yield as the cavity in the salt bed becomes enlarged through the removal of salt and thereby presents a larger area of salt surface for solution. Owing to its greater specific gravity, the strongest brine is always found at the bottom of the well; and if the pumping is considerable, brine of decreasing strength, or even fresh water, will occupy the upper part of the cavity. The solvent power of the water of course steadily becomes less as full saturation is approached, until it ceases altogether. The result is that more salt is removed from the top of the bed than from lower down; and thus the shape of the cavity should become that of a funnel or shallow inverted cone, depending somewhat on how the well is pumped, whether so fast as to yield weak brine or not. This has proved to be what really happens. Wells bored at from 40 to 60 yards distance from old wells have found the cavity already formed, and of a depth which, considered in relation to the salt removed, confirmed this theory. In another case a fall of rock broke the well tubes. The fallen stone was drilled through, and fresh tubes inserted to the cavity beneath it. After the pumping had been resumed, the stone slipped down 1½ feet, breaking the tubes again. It was again pierced, and the process repeated until the stone was lowered 6 feet, showing that solution of the supporting side of the funnel had allowed the stone to slip down. Last, but perhaps not least, an abandoned cavity at Nancy having been pumped dry was entered, and found to be of the shape indicated. It is obvious that the funnel shape of the cavity is an important matter, and an unfortunate one, for pumping, because it removes support from the neighbourhood of the tubes, where it is most needed; and heavy falls of marl and rock occur, which break the tubes, no matter how strong they are, although light falls may be resisted and are known only by the discoloration of the brine. Half-inch steel lining tubes are used; and with this thickness the worst bent and broken tubes after a fall have, with great strain and difficulty, been so far straightened as to be got out by a steady pull with two 50-ton jacks; but in a well with steel tubes of ¾ inch thickness the bend was such that withdrawal was impossible, and the well had to be abandoned. After a fall, weak brine or water is obtained; the invaluable rig is detached from the pumping gear, and is used to withdraw the tubes above the break, generally leaving from 60 to 100 feet in the well. The tools are then strung up, and an attempt is made to drill down by the side of the old tubes and to put fresh tubes in. This operation is often attended with endless perplexities and difficulties; nevertheless wells have been repaired in this way many times. Tools are often lost in this cleaning-out process; in one instance a string of tools, cable and all, went down a cavity, and remain there; and yet the well is working still. The number of wells which have been pumped and afterwards abandoned for various reasons is believed not to exceed twelve; but as most of the wells are of recent date, a larger proportion of loss may be expected in future years.

Yield and Strength of Brine.—Wells vary considerably, both in yield and in strength of brine. This may be due to the existence of earthy matter, which may cover the salt with a coating of mud, and thus check solution; or it may be due to defective couplings or tubes, which would permit dilution of the brine by the entrance of water into the pump tubes from the annular space surrounding them. A well pumping ten hours per day, and yielding 200 tons of salt in brine per week, would be considered doing fairly good work, although wells have been known to yield much more than this.

Surface Subsidence.—The question of possible subsidence of the surface has naturally excited a good deal of interest in Middlesbrough. In Cheshire the flooding of old rock-salt mines and the subsequent pumping, as well as the removal of the mineral from the course of the "runs," have led to serious subsidence, and to extraordinary behaviour on the part of houses, roads, streams, and bridges; but at Middlesbrough the depth of the salt bed is so much greater, and the character of the strata so different, that it does not follow the same results will occur. It is believed that great arches or domes will form themselves over the funnel-shaped cavities in the rock salt, from point to point of support; or that the interstices left between broken masses of fallen rock will equal the bulk of salt removed, and that the surface will therefore be supported. On the other hand it is the opinion of experienced persons in Cheshire that subsidence will ultimately take place; and to this result the experience of mining engineers seems to point. All that can so far be said with certainty is that no sign of subsidence has yet shown itself.

Filtration and Evaporation of Brine.—On reaching the surface the brine is conveyed in pipes to a filter bed, constructed on the pattern of ordinary waterworks sand-filters. These act well, and pass a clear bright brine to the reservoir, whence it is pumped to the pans for evaporation. Notwithstanding the fact that endless efforts have been made to improve the method of evaporation, and that a large number of plans have been devised for this purpose, yet today, just as 1800 years ago, open pans are used, having heat passed under them. The only difference is that the Romans used pans made of lead and not more than a few feet square, while today much larger pans made of steel and iron are employed. The ordinary size of common-salt pans is 60 × 24 feet by $1\frac{1}{2}$ foot deep, as shown in Figs. 11 and 12, Plate 47. The pans are set upon longitudinal walls, which form flues to convey the products of combustion from fire-places at one end of the pan to the chimney at the other. As the water is driven off by evaporation, the salt crystals form on the surface of the brine, and gradually sink to the bottom; they are drawn by rakes to the side of the pan, and lifted out and deposited upon decks or "hurdles," from which the adhering brine drains back into the pans.

Salt.—Fine salt is obtained from brine which is boiled, the fineness of grain depending upon the temperature at which the brine is evaporated: the higher the temperature, the finer the grain; the lower the temperature, the larger the crystals. Block salt or "squares" are obtained by drawing off boiled salt at short intervals into moulds; the squares are afterwards dried by surplus heat from the pans. Table and dairy salt are obtained by grinding squares. Common salt is drawn every other day from brine kept at about 190° Fahr.; fishery is drawn every seven or fourteen days, according to grain, from brine kept at about 100°. All these processes are very simple, yet the salt manufacture is not exempt from difficulties and perplexities any more than other industries.

Discussion.

Mr. Grigg exhibited portions of the "string of tools" described in page 286, including the chisel or bit at bottom, the jars, the rope socket and temper screw at top, and the conical screwed joints coupling them all together. Also specimens of the tubes used for lining the wells, and of suction tubes which had been damaged by falls of rock, and had been recovered from the bore-holes. One of these broken suction tubes, 12 feet long, 3½ inches bore, and ¼ inch thick, had undergone contrary flexure, as shown in Fig. 13, Plate 48, giving it the form of a letter S greatly elongated. Another specimen of broken suction tube, 6 feet long, 3½ inches bore, and ¼ inch thick, had been crushed and flattened at one end and thereby completely closed up, as shown in Fig. 14. A specimen of the sand-pump was shown, together with a collection of samples of the stuff brought up by it, illustrating the nature of the strata bored through. A piece 2 feet long of a large core 8 inches diameter was exhibited, together with two small cores, each about 8 inches long and 4 inches diameter, all of which had been cut and brought up by the diamond drill. A number of samples were shown of the rock salt itself, including a piece transparent enough to read through easily; and also of the several varieties of commercial salt, manufactured from the brine pumped up the wells.

Mr. E. Windsor Richards, Vice-President, remembered hearing from the late Mr. Daniel Godfrey, formerly Messrs. Bolckow and Vaughan's leading engineer, under whose guidance their mining operations had been carried on, that the Middlesbrough salt bed (page 281) had really been discovered by Mr. John Vaughan, who wanted to find out whether there was coal underlying Middlesbrough; but as he thought he should be laughed at if it were known he was boring for coal, he said he was boring for water. When the 18-inch bore-hole which he was putting down resulted in the discovery of the salt, it was thought it would be best to mine the salt rock, and two pits 10 feet in diameter were commenced. After these had been sunk a short depth, large quantities of water were met with, pumps were put in, and the pits were tubbed; but after having got down 80 fathoms the water beat the pumps, the sinking was stopped, and the matter remained in abeyance until Messrs. Bell Brothers took it up, and in their bore-hole at Clarence demonstrated the feasibility of sinking wells as described in the paper (page 281). When operations were recommenced by Messrs. Bolckow, Vaughan and Co., the directors of the North Eastern Railway were naturally anxious as to the safety of their new dock and dock gates at Middlesbrough, in connection with which the question of subsidence of the surface was highly important. At that time he went to Nancy to enquire into the French methods of boring there for salt, and to learn whether there was any danger of subsidence, as this seemed to be the most important point to be considered. At Nancy, where this mode of getting salt by pumping brine from wells had been practised for nearly half a century, there was in the outskirts of the city a fine old cathedral, in which he ascertained there was not a crack to be found throughout the edifice, notwithstanding that the salt getting had been going on round it all that time.

The President asked whether the wells at Nancy were as deep as at Middlesbrough.

Mr. Richards replied that the overlying rock at Nancy was only about 500 feet thick, while in Middlesbrough it was about 1,000 feet thick, and going towards South Bank he believed it was about 1,700 feet thick. Judging from these facts, his own impression was that there need not be much anxiety about subsidence in Middlesbrough.

Mr. Henry Lawrence asked whether it was not a fact that in Messrs. Bell Brothers' bore-hole at Port Clarence water from the waterworks had been sent down to form the brine, because the surface water met with in sinking the hole was not sufficiently pure to make good salt.

Mr. A. L. Steavenson mentioned that, a bore-hole put down by Mr. Casebourne near Seaton Carew having failed to find the salt, it had been determined to take advantage of it to try and find coal; and several firms had joined in the attempt. The boring had then been carried through 878 feet of magnesian limestone, and continued to a total depth of 1,814 feet, where in his opinion it reached the millstone grit, a sample of which was in his possession. It had been supposed by many that the coal beds of South Durham, having risen up to an anticlinal axis, would again be found on the other side, dipping down beneath Cleveland; but this bore-hole had certainly disposed of that supposition, by the failure to find coal at the depth there reached.

With regard to the question of subsidence, although the salt was found at a great depth, its thickness gave much room to fear that a subsidence would occur. But as the spaces from which the salt had been drawn were full of water, which was incompressible, he would suggest that when the bore-holes were abandoned they should be tightly filled with cement. In that way he thought the chances of subsidence would be greatly diminished.

Sir Frederick Bramwell, Bart., Past-President, asked for a somewhat fuller explanation of the way in which the "string of tools" acted in the event of anything going wrong. Assuming for instance that something happened to the leading tool or chisel, he did not understand in what way the succeeding tools could come to its aid to repair the damage. The sand-pump he gathered could only be sent down the hole after the entire string of tools had been withdrawn; and he presumed it was worked altogether independent of them.

The fact that the evaporation of brine should still go on in the manner in which it did, with so large a consumption as half a ton of coal to a ton of salt (page 283), seemed surprising. If the salt were 25 per cent. of the whole brine brought up (page 283), it looked as if a pound of coal was evaporating no more than six pounds of water. In the sugar manufacture, and in the distillation of sea water for the supply of fresh water to ships, the operation was carried out by successive evaporations, known in the sugar industry as the triple or quadruple "effet." Why the same principle could not be applied to the salt industry was more than he could understand; but there remained the stubborn fact that many persons having this information in regard to sugar and in regard to sea-water distillation had tried for years and years to apply it to salt, but without success, and had been compelled to continue the simpler plan now in operation as described in the paper.

Mr. Charles Cochrane, Past-President, considered the question of surface subsidence was a most serious one, and not so easily dismissed as would appear from the operations at Nancy; for it was well known that in South Staffordshire, at a depth of 300 or 400 yards, the ten-yard coal made its effects visible at the surface only too plainly. Here in Middlesbrough the thickness of the salt rock to be excavated was from 50 or 60 feet and upwards; and if the excavation were complete, it seemed to him that one of two things must take place: either by the breaking of the material below in the piecemeal way that had been described (page 290) the cavities might gradually get choked, and but little subsidence reach the surface; or else over the entire area of twenty square miles (page 282) the whole of the strata might together act as a girder to the whole surface, and come down uniformly together. That subsidence would occur must be expected, in view of such a great thickness to be worked out. The suggestion offered (page 290), that arches or domes might perhaps form themselves to support the strata above, was one which he did not quite follow; what was most likely he thought was that the strength of the overlying rocks might enable them to act in girder fashion for supporting the surface, until the time should come when the whole could subside bodily.

Sir Lowthian Bell, Bart., Past-President, having been interested in the manufacture of salt from the beginning, and acquainted with its progress, confessed that he had been considerably alarmed at the idea of removing 100 feet thickness of salt rock, and leaving the surface unsupported, particularly remembering that there was here a highly valuable property and many large works, all dependent upon

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having a sound foundation. He had therefore recommended his colleagues on the board of the North Eastern Railway to send two skilful engineers to Nancy and other places, where salt was removed, if not quite in the same fashion, yet in a manner likely to be productive of the same results. Their investigations on the continent went to show that there was no need to apprehend any disastrous consequences. With regard to the future however he himself was not entirely free from some little apprehension. Even at Nancy the stability spoken of by Mr. Windsor Richards (page 293) was not always to be met with. The salt rock was there worked at a depth in some cases of 300 or 400 feet, in the dry way: that is, it was got by mining, and pillars of it were left in order to support the roof. There was always more or less percolation of water, which got into the workings; and as the salt lay upon shale liable to be affected by atmospheric influence when water was present, the pillars resting upon it began to press down through the softened shale. They went on doing so for some time, and then they rapidly disappeared altogether. They sank down so rapidly that he believed five or ten acres of ground went down with them, accompanied by a noise so loud as to be heard at Nancy, a distance of about twelve miles. He did not apprehend the same amount of danger however as in removing the ten-yard coal in South Staffordshire. There of course the surface stood as long as the pillars were left standing; but after the rest of the coal had all been got, the pillars themselves were removed finally with great rapidity, and it was not wonderful that the whole mass of rock above should descend. In the Middlesbrough district however the conditions were widely different. The depth to the salt rock being as much as 1,200 feet, there was therefore a chance of gradually detached masses of rock falling down, interlocking with one another, and forming a rude sort of arch, as suggested in the paper (page 290). Still the matter was one not to be altogether disregarded. At present not the slightest alteration had been met with in the strata near the surface; and he only hoped that the same state of things would continue.

With reference to the evaporation of the brine (page 294), it could not be pretended for a moment that this corresponded at all with the evaporative power of the coal employed, because even in a high-pressure steam-boiler it was not uncommon for one pound of coal to evaporate eight pounds of water, and sometimes rather more. The brine pans did nothing so good as that; their evaporation of about six pounds of water per pound of coal was considerably below the proper evaporative power of the coal. But coal of inferior quality was here cheap. Although the manufacture of salt appeared to be rough and simple, it was attended with more difficulty than might at first be imagined.

In regard to running waterworks water from Darlington down the bore-holes at Port Clarence (page 293), the surface water which had been used at the beginning was impregnated with a good deal of vegetable matter, and it was found that in the presence of vegetable matter the crystals of salt did not form. In Cheshire he believed it had been found that if a small quantity of oil was poured into a salt pan it prevented the formation of salt altogether. That was quite intelligible, because the evaporation which went on from the surface was thereby more or less stopped, and the crystals of salt did not form. But whatever the explanation might be, the presence of vegetable matter in the water prevented salt from being made in a satisfactory way; and there had been no alternative but to run the Water Company's water down the hole, which was continued for some months. But as soon as the surface water had been exhausted, and the feeders of purer water from the rock beneath began to find their way readily down into the hole, the use of the waterworks water had been discontinued; and now the water from these feeders ran down the hole, and there was no more difficulty in connection with the evaporation of the brine.

In regard to the discovery of the salt bed by the late Mr. John Vaughan (page 292), he had himself as a young man been a pupil of Mr. Vaughan, who was a man of more mature years, and had learnt a great deal from him. The intimate friendship begun in that way had continued during the whole of Mr. Vaughan's life. When

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Messrs. Bolckow and Vaughan found themselves becoming more and more in want of water for their ironworks, Mr. Vaughan mentioned to him that he was determined to sink a well in order to get it. In reply he advised that it was no use doing so, because the well would have first to go through water-bearing strata, full not of such water as was wanted, but of such bad water as would be useless for the purposes desired; but the sinking might possibly come upon a big bed of salt. It turned out as he had predicted: the well yielded bad water, and a good deal of it, and then came upon the bed of salt. He had never heard Mr. Vaughan say anything about getting coal, otherwise he could have told him that he would first have to go through what was known to be a very thick bed of new red sandstone, that he would then probably meet with magnesian limestone, and then the true coal measures at a depth where, judging from all previous experience, it would be physically impossible to work the coal, because the heat at the bottom of a pit of such great depth would be more than men could endure. Under those circumstances he doubted whether Mr. Vaughan had ever intended to search there for coal as suggested.

Mr. HAMMERSLEY HEENAN considered the great hope left for Middlesbrough against surface subsidence lay in the strength of the rock above the salt bed. The cavity formed at every well he presumed must be more or less circular in plan, and falls of roof would cease as soon as they had gone so far as to leave a natural dome over it. Moreover with such a thickness as 1,000 feet of overlying rock, the eye alone could give a good idea of how great would be the strength of a dome of even large span. The conditions seemed to him to be quite different in Middlesbrough from those in the coal districts, because in the latter the ground was undermined in much larger areas, which were of irregular shapes; but in Middlesbrough at every place the excavation was presumably a circle in plan; and the natural dome forming over it appeared to him to be about the strongest possible protection for all the buildings at the surface. What seemed to him to constitute the great difficulty was the protection of the steel tube against damage from the falling roof. When the roof first began to fall he thought it was more likely to do harm than it would later on when the upper portion began to fall away; and some mode would have to be devised of protecting the tube against the accidents described in the paper and exemplified by the damaged tubes exhibited.

Mr. Jeremiah Head, Past-President, considered that, whether or not there were a danger of ultimate subsidence of the surface, there was no likelihood of any such subsidence occurring suddenly. For it appeared to him that the principle of the cataract, whereby sudden motion was prevented by the resistance of water passing through a throttled aperture, applied equally to the salt wells, in which water was always standing in the bore-holes up to a level only slightly below the surface of the ground. Any subsidence therefore could take place only by forcing the water in the workings up through the bore-holes; and inasmuch as the area of the bore-holes was quite insignificant compared with the vast cavities below, it seemed evident that the subsidence could only be gradual, and would be accompanied by the spouting up of water through the bore-holes to a great height. Until therefore lofty geysers were seen issuing from the ground on all sides, there was no need to look out for subsidence; and when it did occur it would be gradual.

Mr. Edward B. Marten, Vice-President, was anxious about the effect of salt working, because he was somewhat responsible for a brick reservoir full of water, at Yew Tree Hill, one mile south of Droitwich, which had been affected by the salt workings carried on there. In that case there had not been any sudden catastrophe, by the reservoir sinking all at once; but one corner was going down gradually every year, and rendering repairs constantly necessary. In the town itself there was a long depressed area of about 200 yards width, which was subsiding, and causing a great deal of trouble to the water pipes and gas pipes. On the north-east side of the town was a line of depression stretching a couple of miles towards Stoke Prior salt works, which were nearly three miles and a half north-east of those at Droitwich; the depression was eighteen to

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twenty feet wide, with walls on each side five or six feet high, and looked like an excavation for an abandoned road. In some of the remarks that had been made (page 298) it appeared to be taken for granted that the salt rock would be dissolved equally all round the well. But he did not see why capricious action might not be expected, the salt dissolving more in one direction than in another, and consequently leading to the same effect of subsidence like a line of trough-fault, instead of within a circular area close round the bore-hole.

Referring to the short samples of rock brought up by the diamond drill, he enquired whether an entire core had ever been brought up from any one of the bore-holes throughout its whole depth. Lately he had seen a good example of sandstone boring at Ashwood near Kingswinford for the South Staffordshire Water Company. The diamond drill had brought up pieces 20 inches diameter and three to five feet long, which had been laid out in a neighbouring field for the purpose of enabling the geologists to judge what part of the sandstone rock had been reached, and thus assist in deciding the probable depth to the coal between the Staffordshire and Shropshire coalfields.

The action of the string of tools seemed rather puzzling, if the motion was given simply by the crank, without any special drop arrangement for the fall of the tool. Was the string of tools let go suddenly, so as to have a free drop? or was it allowed to go down gradually by the motion of the crank?

The doubly bent tube exhibited he supposed was one of those referred to in the paper as having been brought up out of a well; and he asked in what way it was possible for a tube so much bent to be brought up through the bore-hole.

MR. DRUITT HALPIN remarked that, while the evaporation in the salt pans of only six pounds of water per pound of coal was apparently low compared with that of eight or ten to one in good boilers, yet the latter was also low in comparison with the highly economical evaporation of thirty or forty to one by the triple-effect apparatus used in sugar manufacture. One reason he thought why the same results could not be obtained in evaporating the brine was the difference in price of the final product, sugar never going below £10 or £12 a ton at its place of manufacture, which he supposed was a great deal more than salt would fetch.

Mr. John Pattison said it seemed to him that salt production must be an expensive affair here, according to the statements in the paper, taking into consideration the boring of the holes, repairs, constant pumping, and evaporation requiring half a ton of coal per ton of salt. In Sardinia, in the large level plains on the sea shore, the sea water was run into shallow ponds or pans, and evaporated by the sun direct. There was no other expense except that of the labourers' wages, which amounted to fifteen pence a day per man. The supply of material was of course inexhaustible, and there was no danger of subsidence by extracting the salt.

Mr. Grigg pointed out that one objection to the suggested plan of preventing subsidence by sealing the water in the wells (page 294) was that the wells were so near one another as to have become connected, and were still working; and moreover it could not be known when subsidence of so serious a character as to affect the surface might come. If it could be known exactly when that would happen, the wells could be blocked beforehand with cement or other material; but the time could not be known, and it seemed to him that it was impossible to take precautions respecting it, even if it appeared likely that the suggested sealing of the holes would prove effective, which he doubted.

The string of tools (page 294) were all connected by a joint with a taper thread, which screwed very tightly together, so that the entire string of tools acted as one tool, 50 feet long and having a drop of 4 feet; and by its repeated blows it was able to cut its way through any rock, no matter how hard. After penetrating from three to five feet in depth, the string of tools was withdrawn from the hole, and the sand-pump was let down to bring up the grit and mud which had been produced by the pounding action of the blunt chisel at the bottom of the well. The various samples exhibited of the detritus drawn up showed how small the rock was pounded by the chisel.

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The blunt end of the chisel exhibited was exactly the shape in which it worked; it did not commend itself at first sight, but it was really most effective.

One thorny technical point in drilling—about which there was wide difference of opinion, and to which consequently he had intentionally refrained from referring in the paper itself—was the elasticity of the cable, and its effect upon the working of the string of tools in the hole under the action of the beam. In a length of say 1,000 feet of hemp cable there must naturally be a great extent of play due to its elasticity. As a matter of fact the drop of the tools in the hole would probably not be more rapid than the drop of the beam (page 300), because they were falling through water confined in a hole but little larger than themselves. They were therefore practically free-falling tools, so far as their attachment to the beam was concerned, falling without appreciable check from the beam after the crank had turned its bottom centre.

The cores exhibited from borings were only short samples (page 300), and it was quite possible by means of the diamond drill to obtain a greater length of core. At some of the bore-holes this had been done, and the cores carefully preserved, which he should be happy to show to anyone interested who would go there to see them.

The bent suction tubes withdrawn from the bore-holes were the result of falls of rock. One of those exhibited was seen to have been completely closed by being crushed flat, Fig. 14, Plate 48. The other specimen, Fig. 13, which was doubly bent (page 300), had been so far straightened by the strain of withdrawal as to pass through the hole, and had sprung back to its bent form on leaving the hole at the top; at its lower end it would be observed that it must have been at least two feet out of line with the portion above, from which it had been broken off. Sometimes a tube was too much bent to be withdrawn at all, and the hole had to be abandoned and a new one drilled. Lining tubes $\frac{1}{2}$ inch thick and 5 inches bore were sometimes bent nearly as badly as these specimens.

The question which naturally attracted the greatest amount of interest in connection with the subject of the paper was that of subsidence; and he was of opinion that subsidence would ultimately occur at Middlesbrough. Mining engineers and saltmasters of long experience in Worcestershire and Cheshire were nearly unanimous in the belief that subsidence would occur; their opinion had great weight with him, and was so far supported by his own experience at Middlesbrough that he was inclined to believe it would prove to be correct. For in a well reaching the salt bed at a depth of about 900 feet, and carried down further through its thickness of nearly 100 feet, the boring had gone down all the way through solid strata from top to bottom, the overlying rock resting upon the top of the salt bed; yet within five years' working of the well it had been found that the cavity was reached at only 750 feet depth, showing that 150 feet thickness of roof had fallen. This seemed to him a most significant fact. If 150 feet thickness of roof had fallen in five years, why should not the ultimate result be a fall of the entire roof? notwithstanding its having assumed the shape of a dome as anticipated (page 298). Such a dome would be disturbed by the fact that the neighbouring wells communicated, and it was therefore impossible to say where the heel of the arch would ultimately be. The vertical section sketched in Fig. 16, Plate 49, was intended to indicate what was believed to be that of the well referred to, after a second heavy fall of roof and breakage of tubes. The horizontal dotted line AA represented the level of the top of the salt bed, and BB the bottom. The broken tube C had been left in after the first fall of roof and breakage of tube. The tube D had been left in after the second fall and breakage. Although the tubes generally broke at only a few feet below the top of the cavity, this was not always the case; small falls often occurred without breaking the tubes; and sometimes the tubes in the cavity, which was generally much larger than in the present instance, were badly bent and broken at the bottom of the cavity. Just prior to a fall the cavity was always larger than after it, because the material composing the previous falls had found a lower level owing to the removal of the supporting salt by the continued pumping. In Fig. 16 it would be seen that the cavity was at present only five feet deep, which was the smallest in his

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experience. An attempt would be made to drill down alongside the broken tubes C and D, and to insert others; but a time must come when this could not be done again, owing to the presence of numerous broken tubes in the well, when the hole would have to be abandoned.

In the vertical section sketched in Fig. 15, Plate 48, was shown what was presumed to be the shape of a new well, after it had been pumped for a short time, and before the first fall of roof occurred. The water flowing down the bore-hole from the overlying strata would spread all round at the top of the salt bed; and the brine being pumped out from the bottom, his impression was that the cavity would not be a cone having straight sides, but would have curved sides as indicated in the sketch. In one well, where a large block of stone had fallen, it had been pierced where it lay, and the brine had been pumped from below it, with the result of widening the well gradually at that part and lowering the stone about 18 inches from time to time. The size of the stone was believed to be limited in horizontal dimension to probably not more than 8 to 12 feet, because it was found to be only 3½ feet thick, and if it had been larger it would have broken by its own weight; whereas it stood being bored through in its place, and never budged or broke under the operation. Wells had also been put down within such short distances of one another that a later hole had come down into the cavity already formed by an earlier; and the measurements obtained were such as seemed to indicate the shape of cavity sketched in Fig. 15. It was natural to assume that the fresh water coming in at the top of the cavity would spread sideways in all directions along the top of the brine at first, and would find its level lower down afterwards in proportion to its degree of saturation. The solvent power of the water would naturally be the greatest at the top. The wells were perhaps not always of equal extent all round; there might be on one side materials more solvent than on another. It was therefore impossible to say what was the exact shape of the cavity; but it must be something like what was sketched in Fig. 15, both from theory and from the experience that had been obtained. It was probable that ultimately the blocks of sandstone which fell from the roof, and were always lying in water under the pressure of those above them, would lose their sharp angles on which they were at first supported; when they did so, that means of support for the superincumbent strata was gone, and they would depend entirely upon a dome or arch, about which there could be no certainty as to whence it sprung or whether it would always continue to spring from the same points. The question of surface subsidence was a serious one, involving some degree of risk; but a good many of the Middlesbrough salt workings were in fields far away at present from valuable property at surface; and no doubt whenever subsidence came it would come gradually, as suggested by Mr. Head (page 299), and it might be many years yet before it occurred. The experience of Droitwich, referred to by Mr. Marten (page 299), showed that the underground cavities might assume capricious shapes. But it must be remembered that at Middlesbrough, so far as was known, there were no underground streams, no outlets, no runs or drains of natural brine. The existence of any such underground stream running into a river or into the sea might carry away an enormous quantity of the salt, compared with which the brine pumped from the wells would be wholly insignificant. Such a loss might lead to grave results; but he believed it did not in any sense apply to the Middlesbrough district, nor was it likely ever to do so, because the boring operations conducted at surface were here within a few feet of the sea level, while the salt itself was at a depth of say a thousand feet below, and not in a place where there could be a large escape of brine. In Cheshire it was believed that quantities of brine had been escaping for centuries, whereby masses of salt had been carried away.

Mention had been made by Sir Lowthian Bell (page 297) of a fact with which salt manufacturers were familiar both in Middlesbrough and in Cheshire: namely that the least quantity of vegetable matter or of oil in a salt pan produced a film on the brine, which prevented evaporation. This fact was well known by the salt makers, some of whom had occasionally taken a mischievous advantage of it to "poison" a pan by surreptitiously slipping a little bit of butter into it, when for a few hours the pan would be

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doing nothing; the coal would be burning under it without producing any result, the evaporation having been simply stopped by that trifling expedient.

It was true that in Sardinia, as mentioned by Mr. Pattison (page 301), a great deal of salt was evaporated from sea water by the sun. But the difficulty with solar salt was that it was not pure enough; it was mixed with impurities from the bottom of the shallow ponds in which it was made, and therefore it did not give the same results as ordinary salt. A great deal of it was brought to England from Spain, and somewhat interfered with the markets in this country. It was coarse, and well suited for fishery purposes, and a good deal of it was also sent from Spain to Newfoundland for the same purposes. But a large proportion of the fishery salt used in England was evaporated in this country from brine containing 25 or 26 per cent. of salt.

The principle of evaporating under a vacuum in the triple process referred to by Sir Frederick Bramwell and Mr. Halpin (pages 294 and 300) was of no small interest, having been so successfully applied for syrup and sugar; and it had not escaped the attention of those whose anxiety and study it had been to reduce the cost of evaporating brine. Numerous schemes had been proposed with a view of effecting a cheaper evaporation; and attempts had been made to apply the triple process, which he had seen in operation both in England and in America. Persons quite unfamiliar with the subject, having seen the process at work in a sugar refinery, had tried it for salt, and had evaporated brine in that way for a short time; at the end of which the apparatus had become choked, because the salt and lime stuck to the sides. In America something of the same sort had been attempted, and at great cost and trouble an apparatus had been got to work practically, which he had seen in operation. It was successful only to the extent of making salt of extremely fine grain, which was not suitable for ordinary markets. The working involved the constant removal of the tubes used in the apparatus. After a good deal of money had been spent over it, the old plan had finally to be reverted to. In the future however of the salt manufacture at Middlesbrough there was already looming a most important factor, which should not be overlooked. Round the great blast-furnaces here at work there was an immense amount of waste heat; and the question of the utilization of this waste heat was engaging the attention of those most competent to deal with it. At the present time there seemed a reasonable probability that some utilization might be realised of the heat which was now being tumbled away to waste over the ends of the slag tips. The idea of conveying the hot slag-balls on their bogies direct from the blast-furnace into a closed chamber under the brine pan, and admitting also into the chamber a certain quantity of exhaust steam, was forming the basis of a process which was now being got into operation by way of trial at the Clarence Works of Messrs. Bell Brothers, and appeared to give promise of important results. It was obvious that, where half a ton of coal was at present used in the evaporation of a ton of salt, any method by which waste heat could be used would be of the greatest advantage to the salt industry.

If in the visit tomorrow morning to the salt evaporating works at Port Clarence any of the members should wish to see the wells, which were not far distant, he should be happy to conduct them there, and to show them everything else which they might desire to see. These particular works had been chosen for inspection because they were conveniently situated in the line of route for tomorrow's excursion. They were employed wholly on common salt, block salt not being made here. The block-salt works were at Haverton Hill, some two miles away from the common-salt works at Port Clarence.

The PRESIDENT proposed a cordial vote of thanks to Mr. Grigg for his paper, for his admirable series of illustrative samples, for the complete manner in which he had answered the numerous questions, and explained the details of the process of boring and of manufacturing salt, and for his kind offer of facilities in the visit about to be made by the members for seeing the works in operation.

Mr. John Phillips wrote that he did not understand how the pressure of water contained in the cavity at the bottom of a salt well would have any power to hold up the roof, or how by sealing up the well at the top any benefit would result (page 294). The lining tubes were stated to be perforated in the upper part of the well, to permit ingress of water from the sandstone (page 287); and if the water came from the sandstone, the roof of the cavity would have the same downward pressure produced on it by this head of water as the upward pressure resulting from the column of water in the tubes; so that, the water outside and inside the well being at the same height, the roof would be in equilibrium in regard to water-pressure. Under these conditions, should a stone fall from the roof of the cavity, the amount of water displaced by its fall would be equal to the stone's bulk; consequently the water displaced would fill the space the stone fell from. No doubt there would be an agitation of the water; but there seemed no reason to suppose that this would cause a rise of water in the well, or that sealing up the well at the top would prevent the fall of the roof.

DESCRIPTION OF THE ELECTRIC ROCK-DRILLING MACHINERY AT THE CARLIN HOW IRONSTONE MINES IN CLEVELAND.

BY MR. A. L. STEAVENSON, OF DURHAM.
COMMUNICATED THROUGH SIR LOWTHIAN BELL, BART., PAST-PRESIDENT.

Ironstone Mining in Cleveland has now extended over a period of forty years, during the whole of which the writer has been connected and conversant with its progress.

Mining by Hand Labour.—Hand labour has been the general custom; and during the first five-and-twenty years, when skilled men were scarce and new comers had to learn the work, it was usual for a skilled miner to take a novice as an underhand with him, to break up and fill the stone, paying him a datal wage varying from 3*s*. 6*d*. to 4*s*. per shift. These underhands were known amongst the miners as "hagmen." The skill of the miner being exercised in getting as much stone with as few holes and as little powder as possible, the holes are drilled by a long bar or jumper, without the use of a hammer; and as the miner draws it back, by a slight turn of the wrist he cuts a hole of three-cornered section, making it have a flat back or a flat front according as he thinks the stone will cut to the greatest advantage. The holes vary from 3½ to 4½ feet in depth, depending upon the backs or natural vertical cleavages in the stone. To drill a hole of 3½ feet requires about half an hour of steady work; the powder used is about 6 oz. per ton of stone, and the usual price of getting from 10*d*. to 1*s*. per ton. Gradually, as the supply of skilled men overtook the demand, the two miners in each place shared the work and money between them, each man making 4*s*. 6*d*. to 5*s*. 6*d*. per shift.

Hand Ratchet-Drill.—During the last few months, hand drills made to revolve by a ratchet have been introduced, the work being divided between the skilled miner and the filler. These drills promise good results in cases where machines are not available; but the question of prices is not yet definitely decided.

Compressed-Air Rotary Drill.—About sixteen years ago Mr. William Walker of Saltburn introduced a rotary drill worked by compressed air. Of these the writer procured four; and by working double shift, and employing one skilled man to work the drill and another to fire the shots, with unskilled labour to do the rest, he has effected considerable economy. At the Skelton Park Mines of Messrs. Bell Brothers these machines continue doing good work. The writer has always insisted upon the necessity for adopting the Colladon system of cooling the air by water spray during compression; but notwithstanding the marked economy resulting therefrom, the great leakage, arising from the length of pipes of various sizes, which amounts in this case to about eight miles, and from the consequent large number of joints, seemed to present an opportunity for improvement by the use of hydraulic power.

Hydraulic Drill.—At the Lumpsey Mines therefore, where there was a large body of water tubbed back in the shafts 600 feet deep, the writer designed a hydraulic drill to utilize this water, carrying pipes in to the face of the working places. The pressure of 250 lbs. per square inch at the shaft bottom works the drill by means of a small turbine made by Messrs. Gilbert Gilkes and Co. of Kendal, and placed on the machine. This plan has given excellent results; but, as the water has to flow back to the shaft bottom, it can only be used in places to the rise; and moreover it involves the cost of water mains to convey the pressure.

Petroleum Engine.—The writer next introduced the petroleum engine of Messrs. Priestman, and a drill suited to its conditions. Five of these are now in use, and have done good work.

Electric Drill.—When electricity became applicable, its simplicity and regularity in working seemed to offer an inducement for a trial. With the assistance of Mr. Robert Clough, engineer to the mines and collieries of Messrs. Bell Brothers, the writer designed a drill to be worked by this power.

Dynamo.—The current for working the drills is generated at bank by a compound-wound dynamo, having an output of 20,000 watts, and capable of furnishing a current of 50 ampères at a pressure of 400 volts, when running at 900 revolutions per minute. This dynamo is intended to supply current for working the first section of the plant, namely three drilling machines. The current required by each drill varies of course with the hardness of the stone; but it may be taken that under ordinary conditions, and when the voltage at the drills is 300, the current absorbed per drill-motor is about 15 ampères, which is about 6 electrical horse-power; and when a dynamometer was applied to the drill bar, 6 horse-power was obtained. The current from the dynamo is taken to a high-tension double-pole switch on the main switchboard, which is of enamelled slate and has mounted upon it the necessary fuses, measuring instruments, etc.

Cables and Junction-Boxes.—From the switch the current is conveyed down the pit through cables covered with highly vulcanised india-rubber. The cables are run in-bye on insulators, and are kept well in sight, so that, should a fall of stone occur, the damage can be quickly discovered and set right. The main cables are run to a point at a distance of 1,000 yards from the generator; and then from this point branch cables to the different junction-boxes, of which there are six to each drill, commanding twelve working places. The junction-boxes were specially designed to meet the exigencies of the case by Mr. Bigge, and are really a combination of a junction-box, switch, and connecting-plug, as shown in Figs. 11 to 17, Plate 53. The plug is locked in position by a pin, and cannot be withdrawn without first of all lifting the switch, thus preventing sparking and wear on the contacts. Each district to be worked by the several drills is completely wired out and fitted up with these junction-boxes, so that when the drill is moved from one working place to another a box is always to be found within fifty yards distance. The plug at the end of the drill cable is then inserted, the switch on the drill turned on, and within a few seconds the drill is again at work. Much time is saved by this method.

Drilling Machine.—As shown in Figs. 1 to 4, Plates 50 and 51, the way in which the electricity is applied is neat and handy. The motor M is used not only to drive the drill gear, but also to act as a counter-balance to the weight of the drill itself and its gearing. The motor rotates a shaft, which passes through the long hollow carrying-bar C, and by a pair of bevel wheels causes the vertical spindle S to revolve; and a conical pinion on the top of the spindle, gearing into a bevelled wheel on the boring bar B, rotates the drill D. The forward feed of the boring bar is governed by two pairs of retarding wheels RR, Fig. 9, Plate 52, which are geared in such a proportion as suits the nature of the stone. The drill is carried on a circular bed-plate J, which is mounted on the end of the carrying bar C; and it can be turned round by hand when the binding screw is released. As soon as a hole has been drilled the full length of the screw on the boring bar B, the split nut N is opened, Fig. 8, Plate 51, and the boring bar drawn back for inserting a longer drill. In order to reach different heights, the drill can be tilted upwards or downwards by means of the semi-circular arc A, which is moved by a worm. By another worm-wheel W the upright pedestal P can be turned horizontally round its centre. A third worm-wheel L turns the long hollow bar C which carries the drill. The weight of the machine here shown is about two tons.

Motor.—The motors on the drills are shunt-wound, and can easily utilize a current of 20 ampères at 300 volts pressure, giving off about 95 per cent. of what they receive. They are of the Goolden enclosed kind for mining purposes, both the armature and the commutator being completely enveloped in gun-metal cases, which are both gas and dust tight. Even should water pour over them, or a fall of stone occur, they are perfectly protected, and no appreciable damage would be done to them. The brushes used are of special carbon coated with copper. The feed for the brushes as they wear themselves away is automatic, so that they can be run for weeks together without requiring any adjustment or attention. Each drill is provided with a starting switch, placed in the most convenient position on the drill carriage itself, and arranged with resistance coils in such a manner that the drill can be started gradually, and stopped either gradually or instantaneously. Each drill is also provided with a reel of fifty yards of twin flexible cable for the supply and return of the electricity; at the end of the cable is a connecting plug for inserting into the nearest junction-box.

Working.—These electric drills were put into the hands of men who had no previous knowledge whatsoever of electricity; and the day the first drill was put into the mine it was at once set to work at the face, and has been at work ever since. The men are now thoroughly accustomed to the drills, and handle them with the greatest ease. The writer has thus tried almost every method for working drilling machines in ironstone mines, including compressed air, hydraulic power, and petroleum engines; and it is his decided opinion, as the result of this practical experience, that for simplicity in working, ease of transport, speed, facility for extensions, and economy in working, the electric drill has proved itself to be in advance of any other mechanical contrivance yet introduced; and that in the future, where power has to be conveyed to any considerable distance for mechanical drilling, electricity will undoubtedly play the predominant part. The entire work was placed in the hands of Messrs. D. Selby Bigge and Co., electrical engineers, of Newcastle-on-Tyne; and Mr. Bigge devoted considerable time with the writer and Mr. Clough to working out and improving the various details of this the first attempt at electric drilling in the Cleveland ironstone mines.

Output.—The joint output for one week for two of the three machines has already reached 1,577 tons with 790 holes. From 80 to 100 holes have frequently been bored by one machine in a shift, each hole averaging about $4\frac{1}{4}$ feet deep. The miners are enabled to earn 7*s.* 7*d.* each per shift, while the stone is got at a cost of $7\frac{1}{3}$*d.* per ton. Powder is always from one-third to one-half more costly when drilling machines are used than is the case with hand-labour, since it suits better to blow the stone out with a larger number of holes which are quickly and cheaply drilled; this plan also makes the stone fall in smaller blocks, and so saves labour in breaking them up previous to filling.

General Results.—In attempting to compare the results obtained with the several drills, the following considerations have to be borne in mind. The conditions of the seam of ironstone affect the output and cost. An open stone admits of fewer holes in one working place. Then time is lost in more frequent removals of the drill, and the number of holes drilled per hour is diminished.

The cost of the machine itself sometimes represents the whole and sometimes only a fraction of the total cost. Thus a petroleum drill covers the entire cost of its adoption. But the compressed-air drill in some cases has attached to it an average of more than a mile of pipes, and also requires its engine and compressors, as well as its share of boiler. The electric drill also requires engine and dynamo, with a length of cable depending upon the distance from the shaft; it is still so new that alterations and improvements are being made as experience is gained. The hydraulic drill, although getting its power from natural sources, needs pipes; and the exhaust water has afterwards to be pumped up to the surface. The hand ratchet-drill has been applied as yet in only one or two mines, and the tonnage rates and system of working are not yet finally settled with the workmen.

Subject to these considerations the following comparative statement may be taken to represent generally the results thus far obtained with the several drills:—

Description of Drill.	First Cost of Machine only. £.	Holes drilled per hour.*	Ironstone got per shift. Tons.
Hand Jumper	—	4½ ft. in 45 mins.	5 to 8
Hand Ratchet-Drill	3	not yet known	about 18
Compressed-Air Drill	250	about 8 holes	100 to 130
Hydraulic Turbine	220	„ 8 „	100 to 130
Petroleum Engine	375	„ 8 „	100 to 130
Electric Drill	350	„ 10 „	140

* This includes the time lost in moving the machine to different working places.

The length of shift is eight hours from bank to bank, or say seven hours at the face. At the Park Mines the drills work two shifts in 24 hours, and at the other mines one shift; and six shifts per week when trade permits.

Discussion.

Mr. STEAVENSON exhibited specimens of the auger drills used with the electric motor, and of the junction-box and the main and branch cables.

Mr. HAMMERSLEY HEENAN asked what was the diameter of the holes drilled, and whether anything else had been tried for blasting but gunpowder. Would it be practicable to bore much smaller holes, say only half an inch diameter, and use some other highly explosive compound such as roburite? so that with less work as good a result might be obtained. Having himself used a good deal of roburite with half-inch holes, he had found the result was satisfactory. For two mines abroad, with which he was connected, the cost of sending out heavy drills was a serious item, the carriage of everything amounting to sixpence a pound. Gunpowder also was bulky to send abroad; but roburite was now carried at a low freight, because its ingredients were mixed on arrival at their destination without the danger of exploding on the way.

Mr. Harry Shoosmith thought the figures given in page 315 for the cost of the several drilling machines were hardly fair towards the petroleum engine, because the cost given, as there explained, covered in that particular engine the entire cost of its adoption. It would be interesting therefore if the entire cost of the complete machinery for working the rest of the drills could also be stated, say for driving six drilling machines, including all connections such as electric leads or air or water pipes.

Mr. C. Frewen Jenkin asked whether the exhaust gases from the petroleum engine were of a deleterious nature in a confined space; and whether any precautions were needed for exhausting at a distance from where the men were working. In the electric drill he should be glad to know what was the speed of the motor, and what the speed of the drill; and whether the bevelled gearing did not require to be protected with a casing all over.

Mr. Steavenson said the auger drills varied in diameter according to the hardness of the stone; those now shown were about an inch and a half diameter. Of explosives he had tried almost every kind, for every one who had a new explosive came to him wanting him to try it; the best plan he thought was to let them come and try it themselves; and generally, after firing a few shots, they went away satisfied. The last explosive he had tried was bellite, the fault of which was that, though it cut the stone from top to bottom, it still left it standing. All that he had tried had that fault, except one or two which were too slow, so that they came squeaking out of the hole without blasting any stone down and without so much as cutting it. The question he considered had been settled; but if any one would like to try another explosive, he should be glad to give him the opportunity.

With reference to the question of cost, the figure given in the paper for the petroleum machine covered the entire cost; it was fair to say so. The petroleum drills were doing excellent work; but they had one or two faults, in consequence of which they were sometimes a little troublesome. One virtue of electricity was, so far as he had seen it, that it was always reliable. If some one happened to twist the cable and spoil it, there was of course a burnt cable; but otherwise electricity had given entire satisfaction. It was true the exhaust gases from the petroleum drill had given a little trouble, though it had not been serious; but not liking to run the chance of having more, he had preferred to try electricity. As to the gearing in the electric drill, it was not necessarily covered; the motor was covered, but not the gearing. The speed of the motor was about 400 revolutions per minute, and of the auger a little over 100. The great beauty of the drill was that it was set as if it were swung in gimbals; it was important to have it so easily set that it could be put to work in any direction, and could then be clamped firm so that it could not stir. With such a long leverage as that shown in the drawings, it was liable to twist and turn round, if not held firmly enough. By putting a dynamometer brake upon the end of the shaft rotated by the motor, he had found that it gave out six horse-power. Since the drill had been got to work he had reduced the volts to about 200, because he thought the higher voltage of 300 caused a little more trouble with the cable than was necessary. It was now working beautifully; and Messrs. Bell Brothers having allowed it to be brought within a hundred yards of the shaft bottom, those who wished to see it working would have every facility for the purpose in the visit tomorrow to the Carlin How Mines.

The PRESIDENT was sure that the members would give Mr. Steavenson a cordial vote of thanks for his paper on a most interesting subject. He had not only given all the details that were possible by means of the paper and drawings, but had also offered to show the electric drill in operation to any one who desired to see it.

ON SOME ENGINEERING IMPROVEMENTS IN THE RIVER TEES.

By Mr. GEORGE J. CLARKE, of Stockton,
Engineer to the Tees Conservancy Commission.

Communicated through Mr. Thomas Wrightson, M.P.,
Chairman of the Works Committee of the Tees Conservancy Commission.

Tees Conservancy.—Forty-one years ago the Tees Conservancy Commission was constituted by parliamentary authority, and took over the control of the River Tees, together with the liabilities of the then existing Tees Navigation Company. The jurisdiction of the Tees Conservancy extends from well defined limits in Tees Bay to a point in the river at High Worsall, a distance of 25 miles from Tees Bay, Plate 54. The area comprised within their jurisdiction is about 8,000 acres: 7,500 acres in the estuary, and 500 acres above the estuary.

Channel of River.—At one time there were no less than four different channels of the river between Middlesbrough and the sea; these channels were so tortuous, varying, and uncertain that several of the leading lights were placed upon rollers so that they could be the more easily moved as the main channel shifted. The depth of water on the bar in 1863 was $3\frac{1}{2}$ feet at low water of ordinary spring tides. At the present time the depth on the bar is 20 feet at low water, and 37 feet at high water. This material improvement has been effected by the judicious construction of training walls, by dredging, and by the construction of breakwaters.

Training Walls.—At present there are about 24 miles of training walls in the river and estuary; these training walls are carried up to about 5 feet above low-water level, and are constructed entirely of slag from the local ironworks. The greater part of the slag was broken at the ironworks into pieces that could easily be handled, loaded there into keels and punts, and cast out by hand on the site of the work; but, wherever the depth permitted, the broken slag was dropped from hopper barges to form the foundations of the walls. Occasionally during the progress of the work the sand overlying the clay on the site of the walls was scoured away to a depth of 18 or 20 feet; while in some cases the deposit of slag has been continued by keels and hopper barges for a period of six weeks before the wall began to show above low water. The formation of these walls was in progress for twenty-seven years. By the construction of these training walls and the other works referred to, the river at low water is now confined in one channel, as shown coloured blue in the plan, Plate 54.

Breakwaters.—The South Gare breakwater for the protection of the entrance to the river was begun in 1863, and took twenty-four years to build; it is a Portland-cement concrete structure, upon a foundation of slag, with slag hearting between the exterior walls near the head, where it has an extreme width of 220 feet at the level of the roadway. Nearly 5 million tons of slag and over 18,000 tons of cement were used in its construction. The whole structure is upwards of 2½ miles in length. Owing to increased scour in the river and other causes, it has been found necessary to protect the head of the breakwater by a wave-breaker of concrete blocks, varying in weight from 300 tons to 40 tons each.

For the manufacture of the larger concrete blocks, a timber platform was prepared on a suitable part of the foreshore, a little above the level of low water. Upon this platform blocks were built in frames, and when the concrete was carried about half the height of the block, two timber baulks were built into the block; these baulks were laid across the block, with their ends projecting some little distance beyond its sides, so that chains for lifting the block could be readily attached to the timbers. For depositing these blocks two barges were rigidly secured some 20 feet apart by means of two heavily trussed timber beams laid across and secured to the decks of the craft, one beam forward, the other aft; these beams were also used as lifting beams. When a concrete block had to be deposited, the barges were brought to the platform on the early flood tide, and placed so that the block to be removed lay directly underneath the lifting beams and fairly between the barges. The chains attached to the timbers of the concrete block were made fast to the lifting beams; and as the tide rose, the block thus secured was lifted from the platform, and carried where required between the two barges; the barges were then moored, the chains released, and the block dropped into position. Blocks were also built upon launching ways laid across the deck of a barge; the barge so loaded was towed into position, and the blocks launched where required. Large masses of concrete were also deposited by sinking old and otherwise useless craft filled with concrete.

Blocks of 60 to 70 tons are now built on launching ways laid at the level of the roadway of the breakwater, and are launched by screw or hydraulic jacks some two or three months after their manufacture. During stormy weather it has frequently happened that a 60-ton block has been washed off its ways and driven by the sea a couple of hundred feet along the roadway before being finally washed over the side of the breakwater. The glass in the lantern of the lighthouse, 55 feet above the level of high water, has also suffered in stormy weather.

The North Gare breakwater has been completed for a length of 3,330 feet, as shown in the plan, Plate 54, and a return wall formed across the end of the work to protect the slag backing on the harbour side of the breakwater. The structure of the breakwater consists of a solid Portland-cement concrete wall on the sea face, averaging 12 feet in thickness by 26 feet in height. On the harbour face the wall is backed by slag balls for an average width of 50 feet. The slag balls used for backing weigh about 3¼ tons each, and are brought from the ironworks in barges specially constructed for this purpose; each barge carries forty slag bogies on cradles, and each bogie carries a slag ball. The loaded bogies are lifted from the barge by means of an overhead Titan crane, and placed on rails; ten or fifteen bogies are formed into a train and run to the tip head behind the breakwater. About one million tons of slag have so far been used in the construction of the breakwater. This work has been temporarily discontinued, in order that observations may be made of the changes, if any, which may take place in the entrance channel or North Gare sands.

Reclamation of Foreshore.—The reclamation of the foreshore of the river Tees has engaged the attention of the Commission from time to time. The total area of the land at present reclaimed from the foreshore of the river is about 2,400 acres. In 1892 the Commission obtained parliamentary powers for a further reclamation of the foreshore near Port Clarence and Cargo Fleet; this additional reclamation is shown at RR on the plan, Plate 54.

Dredging.—By the combined action of dredging and tidal scour, the increased depth now obtained by the former is maintained by the latter. Since 1854, about 29 million tons of material have been removed by dredging from the bed of the river; nearly the whole of this material has been deposited at sea by hopper barges. The more recent engineering improvements in the river have been the result of increased dredging operations, by means of which not only have deep-water berths been formed in the river at Port Clarence, where vessels drawing from 15 to 21 feet may safely lie afloat at low water, but also the navigable channel has been considerably widened, deepened, and improved. It is intended to construct a channel having a low-water depth varying from 12 feet at Stockton to 15 feet at Middlesbrough, and maintaining at least the latter depth from Middlesbrough to the sea. The total length of channel to be thus deepened, widened, and improved, is about 12 miles; and the whole of the work in connection therewith is in a forward state of progress towards completion.

During the two years ending October 1891, the total amount of material dredged from the bed of the river was nearly 3,700,000 tons. At that time the Commission kept fully employed a fleet of six powerful dredgers, namely five double-ladder dredgers and one single-ladder dredger; also between forty and fifty hopper-barges carrying from 200 to 300 tons each, and nine steam tug-boats for towing the barges to sea. The shortest distance towed was about 10 miles; the longest 31 miles. The greater part of the material removed by dredging consisted of stiff boulder clay; but no less than 302,000 tons of rock—gypsum with red sandstone—were removed by one dredger alone, without the aid of any explosives whatever. During the summer months dredging operations were carried on by night as well as by day. An immense number of old oak tree trunks 60 and 70 feet long, boulder stones up to 7¾ tons weight, horns and bones of various animals, also some ancient human remains, have been dredged from time to time out of the bed of the river.

The larger dredgers have double ladders working in wells, and are capable of excavating to a maximum depth of from 33 to 34 feet. Their principal dimensions are, length from 125 to 140 feet, breadth 34 to 34½ feet, moulded depth 9½ to 10½ feet, length of bucket ladder 72 to 80 feet. As a rule 36 to 40 buckets are placed on each ladder; the capacity of each bucket is 9 cubic feet; the buckets with their links, pins, bushes, &c., are all interchangeable amongst the various dredgers. The engines on the dredgers are single-cylinder jet-condensing, of from 50 to 55 H.P.; the cylinders are 35 inches diameter by 40 inches stroke. All the dredgers are fitted with steam-winches fore and aft, having the usual differential gearing, so that the movement of the dredger may be regulated either longitudinally or transversely. When dredging rock, five or six buckets are removed from each ladder, and replaced by heavy forged-iron or cast-steel claws, there being generally about six buckets between each pair of claws. For many years cast steel has been largely employed in the construction of the working parts of the dredgers. The upper and lower tumblers are of steel, cast in one piece; these castings weigh 23 and 35¾ cwts. respectively; the backs and mouthpieces of the buckets, also the links, pins, bushes, and spur pinions are of cast steel; the tumbler shafts and ladder roller-spindles are of forged steel; the bodies and bottom plates of the buckets are of 3-8ths inch steel plate. The various parts of the buckets and attachments are drilled, turned, punched, stamped, riveted, and put together at the Commissioners' workshops. The crew of a double-ladder dredger usually consists of nine men: namely one master, one engineman, one fireman, two laddermen, three winchmen, and a cook; but while dredging clay, two additional men are employed to loosen the clay in the buckets as they pass the level of the deck of the dredger.

The hopper barges are built of iron. Their principal dimensions are: length about 90 feet, breadth 27 feet, depth 11 feet. They have six doors, three on each side, hinged to the keelson; each door is about 8½ feet long by 6 feet wide. The doors are raised by hand-winches arranged on the after deck of the hopper. Two men are required for each hopper barge. The tugboats used for towing the hopper barges are mostly double-engine paddle-boats of from 40 to 60 horse-power, and carry a crew of five men: one master, two enginemen, one fireman, and one deck hand.

So many and so varied are the factors affecting the cost of dredging—the nature of the material to be removed, the depth of cut which may be made by the buckets at each revolution, the depth of the cutting required, the exposure of the situation, the length of time during which work may be carried on each day without interruption, the distance to which the material has to be towed, &c. —that only the most general comparison can be made of the cost of dredging at one place with the cost of dredging at another. On the Tees alone, the cost of some of the dredging done during the year 1891–92 varied from 4*d.* to 20·4*d.* per ton, while the average cost of the whole year's dredging was 8·62*d.* per ton. During the same period the cost of towage varied from 1·65*d.* to 4·98*d.* per ton. The cost of dredging here given includes the cost of the disposal of the dredgings, the cost of all wages, coals, stores, repairs, chains, tow-ropes, &c., for dredgers, tugs, and hopper barges; but is exclusive of the first cost of the dredgers, tugs, and hopper barges.

Graving Dock, Slipway, and Repairing Shops.—These are situated at Cargo Fleet near Middlesbrough, at S on the plan, Plate 54. The graving dock is 555 feet long measured upon the keel blocks; the entrance is 50 feet wide, with a depth of 15½ feet on the sill at high water of ordinary spring tides. The dock can be divided into compartments by timber booms, the ends of which are fitted into recesses formed in the side walls; it is thus made available, when necessary, for accommodating two or more vessels at the same time. From seventy to eighty vessels, representing about 100,000 tons, are docked here annually. The slipway and gridirons are used almost exclusively for the various crafts belonging to the Commission. The repairing shops, blacksmiths', carpenters', boat-builders', &c., are close to the graving dock; and here are executed the whole of the repairs to the dredgers, steam tugs, hopper barges, and other plant; the shops are suitably equipped with lathes, planing, slotting, shearing, and punching machines, steam hammer, plate-bending rolls, drilling and screwing machines, &c.

Lighting of Channel.—There are altogether fifteen lights upon the Tees:—one white revolving flash-light in the light-house at the end of the South Gare breakwater, visible for a distance of 10 miles; two red leading lights at the fifth buoy, two similar lights at the ninth buoy, two green lights, four fixed white lights, one occulting white light, two gas buoys, and a pilots' shelter. Of these, the two gas buoys, the pilots' shelter, and three of the beacon lights are supplied with compressed oil-gas, each having a storage capacity available for six weeks, burning day and night continuously. The application of this illuminant, instead of oil, is now being extended to the whole of the lights on the river, with the exception of the South Gare breakwater light, and the fifth-buoy leading lights. The gas is manufactured by the Commission at their Graving Dock Works at Cargo Fleet. A barge carrying two large welded storeholders, having a total storage capacity of 900 cubic feet, is specially reserved for the purpose of refilling the cylinders of the various lights; these storeholders are charged at the gas works with a pressure of ten atmospheres, and towed from light to light as occasion requires; the pressure in the storeholders is sufficient to recharge the cylinders of the lights by simply connecting them through a flexible pipe. The barge containing the storeholders is kept always afloat with the storeholders fully charged. The gas lighting is on Messrs. Pintsch's principle; and the whole of the appliances have been supplied by them.

Moorings.—There are altogether about a hundred mooring buoys in the river and estuary, the property of the Commission, besides some forty mooring dolphins. The more recent mooring buoys are made of mild steel plates, with cast-steel cross-heads and nuts, and forged-steel spindles and shackles; they are 8 feet diameter by 9 feet long. Both the ebb and flood buoys in a berth are secured by a 3-inch stud chain, shackled to three bridle-chains which lead from three piles placed in the form of a triangle; these piles are driven well below the surface of the river bed.

Floating Hospital.—The site H for the Tees floating hospital, a short distance below the quarantine station Q, Plate 54, is now being constructed by the Commission at the cost of the port sanitary authority. At this point a portion of the training wall on the western side of the channel has been curved back some 200 feet from the river line, the old training wall removed, and the site dredged out, so that safe access to the hospital may be secured at any state of the tide. The curved portion of the slag wall will be carried up 4 or 5 feet above high water, so as to afford as much shelter to the hospital as possible.

Results of Improvements.—As some indication for the development of the river, it may be of interest to note that the largest cargo shipped from Middlesbrough Dock in 1864 was 708 tons. The largest in 1891 was 5,000 tons, while in 1892 a vessel with 6,500 tons dead-weight cargo left the river.

Briefly it may be stated that by the energy, enterprise, and forethought of the Tees Conservancy Commission, an exposed and dangerous estuary has been converted into a safe and commodious harbour of refuge; a shallow, wandering, and uncertain river has been converted into a safe navigable waterway; and a large tract of waste and useless foreshore has been reclaimed, and made available for profitable and useful purposes.

Discussion.

Mr. Jeremiah Head, Past-President, was impressed, as he had no doubt were the members generally, with this excellent and useful paper, recording what had been done in the best and cheapest possible way on one of the greatest works in the country. One detail had specially interested him, living as he did at Coatham near Redcar: namely the recent fixing there of a gas buoy at the Salt Scar, which was a reef of rocks extending about a mile from the shore. On that shore he had seen no fewer than six wrecks at one time. There were two piers, one at Redcar and the other at Coatham; he had seen one of them after a storm with two gaps in it and the other with one gap, while three ships were lying on the lee side of the piers, having gone right through them. It was therefore, as would be seen, a rather dangerous coast; and the residents were glad to have something which, when the wind blew on shore, would warn the ships of the proximity of those dangerous rocks. The gas-buoy, as mentioned in the paper, was charged about every six weeks, and the gas burned day and night. It had also a mechanical apparatus, by which it showed an intermittent light. Since it had been put there, no wrecks had occurred; and he hoped it would continue to keep ships off the shore. It might seem rather wasteful that the gas, which was put there at some expense, should be burning all day as well as all night; but that was because of the impossibility of regulating the supply to suit the varying lengths of the nights. The only way at present known, he supposed, was to burn day and night continuously; the light was sure to be there when it was dark enough to see it. There were also other gas-buoys in the river, as mentioned in the paper (page 324).

The construction of concrete breakwaters at the South Gare and the North Gare—the body of the concrete being composed of slag from the blast-furnaces—was a feature which, he believed, naturally originated in this district, so large a quantity of slag being made in the immediate neighbourhood. It had proved a double blessing. It had afforded a means of advantageously disposing of some of the slag by which the blast-furnaces had been so seriously encumbered. It had also converted the river from one which forty years ago could be walked across at low water at the bar, into a magnificent waterway where ships of as much as 6,000 tons could go in and out, even in a laden condition, with perfect safety. There could be no doubt that the money spent upon the river had been an enormous advantage to the commerce of the Cleveland district. The trade was said to follow the flag; and to have a port like Middlesbrough, navigable for ships of any practical size, which could go to the most distant parts of the world, and could come in and out and load with perfect safety, must evidently be an enormous advantage. It induced trades of all kinds to spring up, wherein the iron of the district was manufactured into commodities which were required, and which could be put free on board in the Middlesbrough Dock, and sent away to the ends of the earth. No doubt the position of Middlesbrough in this respect was now particularly good. The ironstone was got from the neighbouring hills; the coal and coke of the Durham coalfield were close at hand; and the manufactured iron and steel thereby produced here, together with the salt now made, instead of being sent as formerly to Hull, Newcastle, Sunderland, or some more distant port, could at a cost not exceeding 2*s.* 6*d.* per ton be put on board the vessels in the Middlesbrough Dock, and sent direct to India, China, Japan, or elsewhere. The Cleveland district was therefore exceedingly indebted to the Tees Conservancy Commission and their able engineers for what they had done in the way of converting their originally poor and shallow river into one of the first and best estuaries in the world.

Mr. CHARLES COCHRANE, Past-President, noticed it was stated in the paper (page 323) that, while dredging clay, two additional men were employed to loosen the clay in the buckets as they passed the level of the deck of the dredger. The first attempt to substitute steel for wrought-iron in dredger buckets he believed had threatened to be a complete failure; but when the steel buckets came to be examined,

(Mr. Charles Cochrane.)

it had been found that the necessary holes had been forgotten to be made in the back or bottom of the buckets, for letting the air in behind the clay, and so allowing the clay to slip out. In the present instance he should be glad to know whether proper provision had been made by means of holes in the buckets, so as to render it unnecessary to employ two extra men to help in clearing them out.

Dr. John Ryan asked whether the reclamation already effected of 2,400 acres from the foreshore of the estuary (page 321), and the further reclamation intended near Port Clarence and Cargo Fleet, did not involve the sacrifice of much tidal scour. In some rivers he believed it had been thought worth while to preserve special reservoirs, and to maintain such spaces as already existed, for the sake of the tidal scour. In the upper reaches of the Tees itself, it seemed to him from the plan as if there were not any great quantity of water likely to be serviceable in this way.

Sir Frederick Bramwell, Bart., Past-President, remembered that in 1843, exactly fifty years ago, when as a young manager of Mr. Hague's factory he had built a locomotive of the great weight of ten tons, it had been purchased for the Stockton and Darlington Railway, and had been brought down as deck cargo on a paddle steamer called the "Emerald Isle," then the only steamer trading between London and Middlesbrough. It was landed at Middlesbrough in the small, tortuous, and shallow river of those days, and put upon the line. Having driven it between Stockton and Darlington, and got his money, he returned to London by coach. That was his reminiscence of the river Tees fifty years ago.

The training walls (page 318) were a subject in which he was much interested, because seven years ago he had been concerned in the very considerable discussion before parliamentary committees as to the effect of half-tide walls in rivers, and he himself went to see their effect in the Seine at Havre. The engineer who designed those walls he believed had said that there would be no appreciable diminution of the tidal water in the river for the purposes of scour under 38,000 years. But after 38 years had elapsed, the evil effect was most marked, and was so very serious that the question of making a new entrance to the port of Havre was under consideration: though he did not know what had since been done. Great use had been made of the injury inflicted on the Seine by the training walls before the parliamentary committee, in opposition to the first suggestion of the Manchester Ship Canal Co. that they should be allowed to obtain an act authorising them to make a canal having its mouth in the Mersey as high up as Runcorn, without any means being provided for the passage through the shallows of the upper Mersey to the sea. Liverpool pointed out that, if that act were accorded to the company, application would be made next year for the power to make a channel from Runcorn to the sea; and it was obvious that the proposition would be to have half-tide training walls from Runcorn to deep water. The committee were told that if that were done it would ruin the whole Mersey, both for Liverpool and for Manchester: and he firmly believed that would have been the case. The committee were also told, not that Manchester should not have a ship canal if she wanted one, but that the right way was to bring the canal along on the land until it had reached a point on the river Mersey whence ships could go to sea, and that thus the half-tide training walls might be dispensed with. The act was not obtained. Next year the company came to parliament with a plan embracing the half-tide walls; again they failed to obtain an act. At length in the third year the Canal Co. came to parliament for power to execute the works now in hand. People often said what an extremely bad tribunal a parliamentary committee was, for it was only after three years that Manchester had got her ship canal. But those who said so did not know the facts he had mentioned: namely that in the first year the Canal Co. had come with an incomplete scheme; that in the second year they came with a complete scheme, but one of a character which would have been fatal; and that in the third year they at length came forward with a scheme which their opponents had told them was the only one that ought to be permitted. These things he considered ought to be borne in mind when the action of parliamentary committees was criticised.

The President regretted that the author had not been able to be present; he had kindly come over yesterday from Stockton to explain that he feared he might have to go elsewhere this morning. In his absence however he was sure the members would wish to pass a vote of thanks to him for his interesting paper, and still more for the visit which they would pay to the works of the Tees Conservancy Commission, and in which no doubt Mr. Clarke would be able to accompany them.

Mr. Clarke wrote that he agreed with Mr. Head (page 326) about the gas buoys, that it seemed rather wasteful to continue burning the gas at the same rate day and night. The Commission had under consideration at the present time an automatic apparatus for turning the supply of gas off during the day and on during the night; but whether or not it was possible at a reasonable cost to construct such an apparatus for beacon or land lights, it was not possible, in his opinion, to apply it to act with certainty upon gas buoys in an exposed situation, such as the estuary of the Tees, where in stormy weather the buoys were buffeted about for days together, with the lantern plunging frequently under water. The bell buoy with occulting gas light at the Salt Scar rocks near Redcar was supplied in duplicate by the Trinity House, the Commission undertaking to supply the gas &c. free of charge.

The dredger buckets referred to by Mr. Cochrane (page 327) the writer is under the impression were made entirely of cast-steel. In the present instance steel plate has simply been substituted for wrought-iron; and all the buckets on each dredger have the necessary holes for allowing water to drain out and air to enter. The clay being dredged however is so stiff and tenacious that the holes in the buckets are not of themselves sufficient to overcome the adhesion of the clay to the sides of the buckets.

The reclamation already effected of the foreshore (page 328) has had no deleterious effect upon the tidal scour. The high-water area of the estuary, measured between Port Clarence and a line joining the heads of the breakwaters, is about ten square miles. With this large area available for tidal scour, combined with the favourable shape of the estuary, no apprehension of any unfavourable action need be entertained in connection with the further reclamation intended at Port Clarence and Cargo Fleet.

Sir Frederick Bramwell's reminiscence (page 328) of the Tees of fifty years ago is exceedingly interesting. The construction, but more especially the alignment, of training walls is a fertile subject of discussion. Unfortunately cases exist where their construction has been prejudicial; but the writer has much pleasure in saying that on the Tees it has been altogether beneficial.

EXCURSIONS.*

On TUESDAY AFTERNOON, 1st August, after luncheon in the crypt of the Town Hall, the Members proceeded by special free train to Newport Station, to visit the following Works in the Ironmasters' district, west of Middlesbrough (pages 337–347):—

Sir B. Samuelson and Co., Newport Blast Furnaces.
Messrs. John Hill and Co., Newport Rolling Mills.
Messrs. Dorman, Long & Co., Britannia and West Marsh Steel and Iron Works.
Messrs. R. P. Dorman and Co., Galvanizing and Corrugating Sheet Iron Works, Ayrton Rolling Mills.
Messrs. Gjers, Mills and Co., Ayresome Blast Furnaces.
The North Eastern Steel Co., Basic Bessemer Works.
The Acklam Iron Co., Blast Furnaces.
Edward Williams, Linthorpe Blast Furnaces.
The Tees Side Iron and Engine Works Co., Blast Furnaces.

For the special free trains on Tuesday, Wednesday, and Thursday, the Members were indebted to the invitation of the Directors of the North Eastern Railway.

On WEDNESDAY AFTERNOON, 2nd August, after luncheon in the crypt of the Town Hall, the Members proceeded by special free train to visit the following Works at Cargo Fleet and Eston (pages 348–359):—

Messrs. Wilsons, Pease and Co., Tees Blast Furnaces and Foundries.
Messrs. Cochrane and Co., Ormesby Blast Furnaces.
The Normanby Iron Works Co., Blast Furnaces.
The Cargo Fleet Iron Co., Blast Furnaces.
The Tees Scoriæ Brick Co., Slag Works.
The Clay Lane Iron Co., Blast Furnaces.
Messrs. Bolckow, Vaughan and Co., Blast Furnaces and Steel Works.

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* The notices here given of the various Works &c. visited in connection with the Meeting were kindly supplied for the information of the Members by the respective proprietors or authorities.

In the evening the Institution Dinner was held in the Royal Exchange, Middlesbrough, by kind permission of the Exchange and Cleveland Club Committees, and was largely attended by the Members and their friends. The President occupied the chair; and the following guests accepted the invitations sent to them, though those marked with an asterisk* were unavoidably prevented at the last from being present.

The Right Honourable the Earl of Rosse, K.P., D.C.L., LL.D., F.R.S., Honorary Life Member. The Worshipful the Mayors of Middlesbrough, Thornaby, Hartlepool, and West Hartlepool—Charles Lowthian Bell, Esq.; William Anderson, Esq.; Edward Nixey, Esq.; and Thomas Robinson, Esq.

Reception Committee.—Mr. Jeremiah Head, Past-President, *Chairman.* Mr. John Dennington and Mr. Thomas Mudd, *Honorary Secretaries.* Mr. H. T. Allison; Mr. R. H. Appleton; Mr. William Ashmore; Mr. Jonathan E. Backhouse*; Mr. C. J. Bagley*; Mr. George Bainbridge, Town Clerk; Mr. G. H. Baines; Mr. J. Phillips Bedson; Mr. J. T. Belk,* Coroner; Mr. William Belk*; Sir Lowthian Bell, Bart., Past-President; Mr. Hugh Bell; Mr. R. Seymour Benson; Mr. Thomas Bower; Mr. Joseph E. Brooks; Mr. J. W. Brown, Borough Surveyor, West Hartlepool; Mr. William Charlton; Mr. Herbert Cheesman; Mr. George J. Clarke,* Engineer, Tees Conservancy; Mr. Alfred O. Cochrane*; Mr. Charles Cochrane, Past-President; Mr. C. J. Coleman,* Stipendiary Magistrate; Mr. J. V. Cooper; Mr. Ernest H. Craggs*; Mr. William C. Craggs; Mr. G. Butt Craig; Mr. W. J. Cudworth, Resident Engineer, North Eastern Railway, Darlington; Colonel Davies; Mr. Alfred C. Downey; Mr. David Evans; Mr. John R. Fothergill; Mr. Christopher Furness, M.P.*; Mr. John Gjers*; Mr. Lawrence F. Gjers*; Mr. Matthew Gray*; Mr. Thomas M. Gray*; Mr. Richard Grigg; Mr. Edward Hamilton*; Mr. William Hanson; Mr. J. B. Harper,* Passenger Superintendent, North Eastern Railway, Darlington; Mr. Joseph H. Harrison; Mr. Alexander T. Harvey; Mr. William Hawdon; Mr. Archibald P. Head; Mr. C. Arthur Head; Mr. Christopher Heslop;

Mr. Walter S. Hill; Mr. Richard Howson*; Mr. James Hutchison*; Mr. James I'anson; Mr. W. Porritt Ingham; Major Robert Irvine; Captain Johnson, Board of Trade Surveyor; Mr. Walter Johnson; Mr. E. A. Jones; Mr. Archibald S. Keith; Mr. Edward Kirby; Mr. E. D. Latham,* Borough Engineer; Mr. J. Milner Lennard; Mr. Angus Macpherson; Mr. F. Herbert Marshall; Mr. Samuel Marston; Mr. William Moore; Mr. D. B. Morison*; Mr. Robinson Murray; Mr. W. H. Panton*; Sir Joseph W. Pease, Bart., M.P.*; Mr. Arthur Pease; Mr. H. Pike Pease; Mr. J. Francis Pease*; Mr. Thomas Putnam*; Sir Hugh Gilzean-Reid; Mr. Philip Reid*; Mr. E. Windsor Richards, Vice-President; Mr. William Richards*; Mr. Thomas Richardson; Mr. Thomas D. Ridley; Mr. Edward Robson; Mr. John Rogerson*; Mr. Robert Ropner, Jun.*; Colonel S. A. Sadler; Mr. Francis Samuelson*; Mr. G. Scoby-Smith; Mr. C. J. Seaman; Mr. J. E. Stead*; Mr. A. L. Steavenson*; Lieut.-Colonel John Stevenson; Mr. Walter W. Storr; Mr. E. W. Swan*; Mr. Herbert A. Swan; Mr. J. G. Swan; Mr. George Taylor*; Mr. David Terrace; Mr. John Thomson*; Dr. C. Otto Trechmann; Mr. William Walker*; Mr. William E. Walker*; Mr. Tom Westgarth; Mr. Eugene Wethey; Mr. A. H. Whipham*; Mr. Illtyd Williams; Mr. J. Begby Williams*; Mr. Charles Willman*; Mr. Isaac Wilson; Mr. J. F. Wilson; Mr. R. Theodore Wilson*; Mr. J. R. Winpenny; Mr. R. J. Worth; Mr. James Wright; Mr. Thomas Wrightson, M.P.*.

Mr. D. Selby Bigge; Mr. D. W. Dixon; Mr. J. Gilchrist; Mr. Arthur T. Griffin*; Mr. James Hogg*; Mr. Henry Simpson, Secretary, Middlesbrough Chamber of Commerce; Mr. Alfred Sockett,* Deputy Town Clerk; Mr. J. D. Williamson.

The President was supported by the following officers of the Institution:—*Past-Presidents,* Sir Lowthian Bell, Bart., F.R.S., Sir Frederick Bramwell, Bart., D.C.L., LL.D., F.R.S., Mr. Charles Cochrane, and Mr. Jeremiah Head; *Vice-Presidents,* Mr. Edward B. Marten, and Mr. E. Windsor Richards; *Members of Council,* Mr. John A. F. Aspinall, Mr. Edward P. Martin, Mr. William H. Maw, Mr. James Platt, Mr. William H. White, C.B., LL.D., F.R.S., and Mr. J. Hartley Wicksteed.

After the usual loyal toasts proposed by the President, Sir Lowthian Bell, Bart., proposed "The Houses of Parliament," which was acknowledged by the Right Hon. the Earl of Rosse, K.P., Honorary Life Member. The toast of "The Mayor and Corporation of Middlesbrough," proposed by the President, was acknowledged by his Worship, Charles Lowthian Bell, Esq. Sir Frederick Bramwell, Bart., Past-President, proposed the toast of "The Iron and Steel and Engineering Industries," which was acknowledged by Colonel Davies and his Worship the Mayor of Thornaby-on-Tees, William Anderson, Esq. The toast of "The Reception Committee and the Honorary Secretaries," proposed by Mr. Edward B. Marten, Vice-President, was acknowledged by Mr. Jeremiah Head, Past-President, Chairman of the Reception Committee, and by Mr. John Dennington and Mr. Thomas Mudd, Honorary Secretaries. Mr. E. Windsor Richards, Vice-President, proposed "The Cleveland Institution of Engineers," which was acknowledged by Mr. William Hawdon, President of the Cleveland Institution. Mr. J. Hartley Wicksteed, Member of Council, proposed the toast of "The President," by whom it was acknowledged. The toast of "The Secretary" was proposed by the President, and acknowledged by Mr. Alfred Bache.

On THURSDAY, 3rd August, an Excursion was made across the river by ferry to Port Clarence, to visit Messrs. Bell Brothers' Blast Furnaces (pages 359–361); and the Brine Evaporating plant of the Salt Union, Port Clarence Salt Works (page 361). Thence by special free train to Thornaby to visit the following works (pages 362–9):—

Messrs. William Whitwell and Co., Thornaby Iron Works.
Mr. R. W. Crosthwaite, Union Foundry.
Messrs. Head, Wrightson and Co., Teesdale Iron Works.
Messrs. Appleton, French, and Scrafton, Cleveland Flour Mill.
Messrs. Craig, Taylor and Co., Thornaby Shipbuilding Yard.

An alternative Excursion was made by free train to Saltburn-by-the-Sea, and thence by brakes to visit the following Ironstone Mines:—North Skelton, Lumpsey, Carlin How, and Loftus (pages 369–371).

After luncheon in the crypt of the Town Hall, Middlesbrough, an Excursion was made by special free train to inspect the South Gare Breakwater; and thence to Saltburn to visit the Gardens of the Saltburn Estate, by invitation of the Owners, the Gardens being illuminated in the evening, and music performed there by the band.

On Friday, 4th August, an Excursion was made to visit the Tees Conservancy Works, and the Hartlepools, by special free steamers from Stockton and Middlesbrough, by invitation of the Tees Conservancy Commissioners. An opportunity was thus afforded of viewing in passing the various shipyards, iron, steel, and salt works on the banks of the Tees, the Middlesbrough Dock, the Estuary of the river, the Fifth Buoy Lighthouse, and the South Gare and North Gare Breakwaters of the Tees Conservancy.

The Members were received at Fish Quay Landing, Old Harbour, Hartlepool, by Mr. Thomas Mudd, Honorary Secretary, and other members of the Hartlepool Reception Committee. Visits were then made to Messrs. T. Richardson and Sons' Marine Engine Works (pages 380–2), under the guidance of Mr. Thomas Richardson and Mr. D. B. Morison; to the Central Marine Engine Works (pages 383–4), under the guidance of Mr. G. H. Baines and Mr. Thomas Mudd; and to Messrs. William Gray and Co.'s Shipyards (pages 384–5), under the guidance of Mr. George Jones. After luncheon at the Royal Hotel, West Hartlepool, visits were made in conveyances provided by the kindness of the Hartlepool Reception Committee to the West Hartlepool Steel and Iron Works (pages 385–7), under the guidance of Mr. Matthew Gray; and the British Metal Expansion Works (page 387), under the guidance of Major Irvine and Mr. McKenzie. Thence the Members returned in the special steamers to Middlesbrough and Stockton in the afternoon.

The Corporation Gas Works, Commercial Street, Middlesbrough, of which the Manager is Mr. David Terrace, were opened to the visit of the Members during the Meeting.

During their stay in Middlesbrough, the Members of the Institution were made Honorary Members of the Cleveland and Erimus Clubs, by the kindness of their respective Committees.

SIR B. SAMUELSON AND CO., NEWPORT IRON WORKS, MIDDLESBROUGH.

These works, situated at A, Plate 55, may be divided into two portions: the western or older portion, built in 1863 and comprising five blast-furnaces; and the eastern or newer portion, built in 1870 and comprising three blast-furnaces. The eight blast-furnaces are from 84 to 85 feet high, with boshes varying from 20 to 28 feet diameter. One furnace has recently been re-lined upon Messrs. Hawdon and Howson's plan (page 263), having three boshes or shoulders, varying from 20 to 25 feet diameter; it is said to give excellent results, yielding no less than 700 to 800 tons of Cleveland iron per week.

Blast at a pressure of 5½ to 6 lbs. per square inch is supplied by two double and eight single blowing engines. Two furnaces in the western group are blown independently, each by its own engine; but in other cases the blast mains are common to several furnaces. The two double engines are simple non-condensing. Of the eight single engines, five are simple non-condensing, two are compound condensing, and one is simple condensing. The three last have recently been altered from simple non-condensing, and considerable saving in steam has thereby been effected. The blast is heated to a temperature of 1,400° Fahr. by Cowper stoves, of which there are seventeen in all; ten are 54 feet high by 23 feet diameter, four are 64 feet by 21 feet, and three are 64 feet by 23 feet. Steam at a pressure of 65 lbs. per square inch is supplied to the blowing engines by thirty-eight boilers, 35 feet long by 5 ft. 6 ins. diameter, each having a single flue 2 ft. 8 ins. diameter, in which furnace gas is burned. The feed-water is heated by the exhaust steam to 208° Fahr. There are in all thirteen calcining kilns, of which a portion are employed for roasting Cleveland ore, the remainder being used as bunkers for ore. Behind each row of blast-furnaces is a gantry running parallel thereto, and surmounting the kilns and bunkers. The hoists for lifting loaded trucks at one end are worked by a direct-acting steam cylinder, while the drops at the other end are worked by brakes. The furnace hoists which serve the western group are of the water-balance kind; and those which serve the eastern group are worked by winding engines placed in a house above the charging platform.

Three classes of pig-iron are produced, namely:—hematite from Spanish ore; Cleveland from ore obtained from their Slapewath mine near Guisborough, and other Cleveland mines; and basic for use in the Bessemer basic steel-making process, containing about 2¾ per cent. of phosphorus. The outputs per furnace are respectively 800, 700, and 600 tons per week. Each furnace is provided with one of Hawdon's slag machines (Proceedings 1892, page 70), whereby the molten scoria is cooled and loaded into trucks in the form of shingle, which is subsequently deposited out at sea. About 5,000 tons of slag per week are at present dealt with. Belonging to the works is an extensive wharf on the river side, where ore is unloaded and pig-iron shipped; and also a wharf where slag is tipped into hopper barges.

MESSRS. JOHN HILL AND CO.,
NEWPORT ROLLING MILLS, MIDDLESBROUGH.

These works, situated at B, Plate 55, were built in 1864 by Messrs. Fox, Head and Co., by whom they were owned and operated, until in 1888 they were leased by them to Messrs. John Hill and Co., who subsequently purchased and remodelled them. The manufacture carried on is that of iron plates and sheets for ships, bridges, etc. Steel plates and sheets are also rolled from blooms supplied by local steel-makers.

The forge contains fifty puddling furnaces, two 50-cwt. steam-hammers, and a 22-inch forge-train fitted with clutch reversing-gear and a four-cylinder steam screwing-gear. The train is driven by a 28-inch horizontal non-condensing engine. In the mill department there are fourteen heating furnaces, fitted with charging gear worked by a small steam engine through Weston friction-clutches; a blooming mill driven by a pair of 24 × 30 inches vertical engines; and a 28-inch finishing mill containing three stands of rolls, namely roughing, finishing, and sheet rolls. The mill is reversed by a steam clutch, and is driven by an unusually powerful horizontal non-condensing steam-engine with cylinder 48 inches diameter and 54 inches stroke, controlled by Schaeffer and Budenberg's governor and variable expansion-gear. The slide-valve can be put in gear with a special steam-cylinder, and so moved or reversed. There are three plate-shears. The heavier plates are handled by means of chains, which are worked from drums driven by an auxiliary engine. Steam at a pressure of 50 lbs. per square inch is supplied by twenty-four vertical boilers heated by the waste gases from the puddling and heating furnaces. No hand-firing is necessary since the works passed into the hands of the present firm.

The output of the works is about 800 tons of iron and steel plates per week. They vary in thickness from $\frac{1}{8}$ inch up to $1\frac{1}{4}$ inch, and in area sometimes reach 230 square feet.

MESSRS. DORMAN, LONG AND CO., BRITANNIA & WEST MARSH STEEL & IRON WORKS, MIDDLESBROUGH.

The product of the Britannia Steel Works, situated at D, Plate 55, consists of steel joists, tees, angles, and bars of all sections. The steel-melting shop contains ten acid-lined open-hearth furnaces, namely five of 40 tons capacity, which are among the largest in the district, and five of 30 tons capacity. Each is provided with a separate wrought-iron chimney. Gas is generated by producers of the Ingham type. The steel is cast into 3-ton ingots, which are carried by a narrow-gauge railway to the vertical heating furnaces.

The latter are heated by producer gas on the regenerative reversing principle, being provided at each end with a pair of chambers, that is one chamber for air and one for gas. The furnaces can each accommodate from twelve to fourteen ingots, which are introduced and withdrawn by a crane through lids in the top. From the heating furnaces the ingots pass on to the 36-inch cogging mill, which is provided with live-roller gear, and is driven by a pair of 50 × 60-inch reversing engines, made by Messrs. Davy Brothers, Sheffield. The bloom passes thence on live rollers to the hot-bloom shears, capable of cutting a sectional area of 140 square inches. The blooms so cut are taken by a self-moving crane to the re-heating furnaces, each capable of heating a bloom $11\frac{1}{2}$ feet long. When re-heated the blooms are taken by a narrow-gauge locomotive to the finishing mills. The larger of the two mills has lately been provided with live rollers, one set for each stand. They are driven by a pair of auxiliary engines, fitted with friction clutches, by means of which any one set can be put into operation without the rest. The mill is also provided with traversing gear. The joists are sawn to length while still hot; overhead steam travelling cranes are used to take them from the hot bank to the straightening machines, and from the latter to the railway trucks and to the wharf for shipment. The output of steel joists and bars is about 1,500 tons per week. The new girder-shop is fitted with every facility for producing girder work or columns, built up of section bars. Both air and hydraulic riveting are used, but the former is preferred. The largest joists here rolled are 18 inches deep and 7 inches broad. The strength of the material is as follows:—breaking stress 28 to 32 tons per square inch; elongation 20 per cent.; contraction of sectional area 40 per cent.

The West Marsh Iron Works, situated at C, Plate 55, produce iron angles and bars. The forge contains twenty puddling furnaces, one 4-ton steam-hammer, and a 20-inch forge train. The mill comprises eleven heating furnaces, and a 16-inch and a 10-inch mill. The output is about 600 tons per week.

MESSRS. R. P. DORMAN AND CO., GALVANIZING AND CORRUGATING WORKS, AYRTON ROLLING MILLS, MIDDLESBROUGH.

Situated at E, Plate 55, these are at present the only works in the Cleveland district where galvanized and corrugated sheets are made; their manufacture was begun about three years ago. The forge contains thirty puddling furnaces, two steam-hammers, and a forge train. There are five sheet mills with the necessary heating and annealing furnaces. The galvanizing and corrugating department contains the usual pickling troughs, galvanizing baths, and corrugating machinery. The sheets vary in thickness from No. 18 to No. 30 Birmingham wire-gauge, that is from 0·049 to 0·012 inch; in size they can be rolled up to 10 feet by 40 inches. The output is about 200 tons of galvanized and corrugated sheets per week, most of which is sent to India, Australia, and China. The works also produce puddled bars, wedge and packing iron, and black sheets.

MESSRS. GJERS, MILLS AND CO., AYRESOME IRON WORKS, MIDDLESBROUGH.

Situated at F, Plate 55, these works were built in 1870. They comprise four blast-furnaces, each 85 feet high by 25 feet diameter at the bosh, and 8 ft. 6 ins. diameter in the hearth. The present output is about 2,900 tons of hematite and special foundry pig-iron per week, made principally from Spanish ore. Air is supplied to the furnaces by three vertical blowing-engines, having 40-inch steam and 96-inch air cylinders, with 48 inches stroke. These deliver into a common main at a pressure of 5 lbs. per square inch. The blast is then heated to a temperature of 1,100° Fahr. by pipe stoves, of which there are four blocks, each comprising six stoves, and each stove containing fourteen pipes. Steam is supplied to the blowing engines at a pressure of 50 lbs. per square inch by twelve plain cylindrical boilers, 60 feet long by 4½ feet diameter, and four new Lancashire boilers 30 feet long by 8 feet diameter. The flues of the former are all connected to a brick chimney 120 feet high; while those of the latter end in a separate wrought-iron chimney 50 feet high to each boiler. All the boilers are fired by waste gas. The furnace walls are cooled by water-blocks, and also by water trickling over the outside of the brickwork.

The hoists are on the pneumatic principle invented by Mr. Gjers. A central vertical tube or air-cylinder, 36 inches diameter inside, extending from the ground to the charging platform, acts as a guide to the cage. A heavy piston inside, connected with the cage by means of wire ropes and pulleys, counterbalances the weight of the latter and of a set of barrows and of their contents when half full. The top of the tube is open to the air. The lower end is connected through a D slide-valve, worked by hand, with the suction or delivery pipe of an air pump worked by a steam engine. When the cage ascends, the piston is drawn down from the top by a vacuum of about 3 to 5 lbs. per square inch; when it descends, a pressure of about 4 lbs. per square inch forces the piston up to the top.

Behind the blast-furnaces is a gantry 36 feet high, for charging the calcining kilns and mineral bunkers. Of the former there are in all eight, 33 feet high by 24 feet diameter; but of these only one is in use. At one end of the gantry the full trucks are raised by a pneumatic hoist on the principle just described, and at the other end are lowered by a pneumatic drop, the air being made to act as a brake. The works include three wharves upon the river, one for shipping pig-iron, one for unloading ore, and one for taking slag out to sea in hopper-barges.

The following kinds of iron, branded "Ayresome," are made here:—special foundry iron; hematite for either Bessemer or Siemens steel; ferro-silicon; and silico-spiegel.

THE NORTH EASTERN STEEL WORKS, MIDDLESBROUGH.

These works, situated at G, Plate 55, were built in 1883 for the manufacture of basic Bessemer steel by the Thomas-Gilchrist process. They are within a short distance of several blast-furnace works, from which iron may be obtained as pig or in a molten condition.

The Bessemer department contains four 10-ton converters. They are mounted upon a gantry 22 feet high, to which bogie ladles or trucks are raised by two 20-ton hydraulic lifts. There are six cupolas for melting pig-iron, with charging platforms on the gantry level; they are used when molten iron is not obtained direct from the blast-furnaces. On the gantry level are also the tapping holes of the spiegel cupolas, the charging platforms being 12 feet higher, to which the necessary minerals are elevated by means of a 2-ton hydraulic hoist. Behind the converters is the basic shop, where the linings are made for the four portions of the converters, namely nozzle, body, bottom, and plug. The lining consists of shrunk and ground dolomite (magnesian limestone, a double carbonate of magnesia and lime), mixed with boiled tar and baked. The raw dolomite is shrunk in cupolas, into which it is charged with coke, and from which it is drawn at intervals. It is then ground, together with about 10 per cent. of its weight of boiled tar. The ground mixture is formed into bricks, with which the body of the converter is lined. The nozzle and bottom are formed of the same material in a plastic state, rammed in and baked by a fire placed in the centre. The plug is similarly formed by ramming round steel pins, which are subsequently withdrawn, thus leaving the necessary blast-holes; a week's baking completes the plug. Over the converter shop is a 60-ton travelling crane, and over the basic shop a 30-ton. Blast is supplied to the converters by two vertical non-condensing blowing engines, each having a 40-inch steam and a 54-inch air cylinder with 60 inches stroke.

The contents of the converters are poured into one of two ladles carried on hydraulic radial cranes. These transfer the ladle to a central casting-crane, commanding a circular casting-pit 60 feet diameter. The ingots when sufficiently cool are stripped and removed by ingot cranes, of which there are four, and are conveyed to the cogging mill. This consists of a single stand of rolls 36 inches diameter, and is connected by spur gearing with a pair of horizontal non-condensing reversing engines, having cylinders 40 inches diameter and 60 inches stroke. The ingots after being cogged down into slabs or billets are cut by a horizontal shears, and are then conveyed by live rollers to the finishing mill. This comprises two stands of 28-inch rolls, driven direct by a pair of horizontal engines having cylinders 50 inches diameter and 54 inches stroke. The finished rails or bars are then sawn to length, and passed on to the loading bank.

Near the cogging mill are the heating furnaces, which are vertical and coal-fired. There is also a range of twenty-four Lancashire boilers, 28 feet long and 7 feet diameter, working at a pressure of 90 lbs. per square inch. The feed-water passes through economisers, in which the temperature is raised to 250° Fahr. The hydraulic pumping apparatus includes two pairs of horizontal pumping engines with cylinders 26 inches diameter and 36 inches stroke, each cylinder working two 6-inch rams; also two accumulators with 24-inch rams and 15 feet stroke.

The output of the works per week is about 3,000 tons of ingots and 2,600 tons of finished steel. The latter comprises rails, blooms, billets, and bars, for sleepers, tinplates, stampings, wire, nail strips, tubes, etc.

THE ACKLAM IRON WORKS, MIDDLESBROUGH.

These works, which were established by Messrs. Stevenson, Wilson, Jaques and Co. in 1865, are situated at H, Plate 55, and comprise four blast-furnaces, 70 feet high by 22½ feet diameter at the bosh, with usual accessories. The minerals are raised to the charging platform by a winding engine and inclined plane and by a vertical lift. The blast is supplied by four vertical non-condensing blowing engines, two having 48-inch steam and 100-inch air cylinders, and the two others 44-inch steam and 96-inch air cylinders. The blast is heated by Cowper stoves, of which there are twelve. Steam is generated in twelve Beeley three-flued boilers heated by the furnace gases; six of these are 35 feet long by 8½ feet diameter, five are 37½ feet long by 8½ feet diameter, and one is 30 feet long by 8 feet diameter. Behind the furnaces there is a row of eight calcining kilns, 60 feet high by 30 feet diameter, and the usual mineral bunkers. All are surmounted by a gantry, from which the trucks discharge their contents. Basic and Cleveland pig-iron are here produced, the average output per furnace per week being about 650 tons. The company own a wharf having a frontage of 220 feet, for exporting their pig-iron and importing materials. The slag is tipped on an adjacent heap. The works are connected by a siding with the North Eastern Railway. The total number of men employed is about 300.

EDWARD WILLIAMS,
LINTHORPE IRON WORKS, MIDDLESBROUGH.

These works, situated at I, Plate 55, were erected in 1864 by Messrs. Hopkins, Lloyd and Co. to the designs and under the supervision of Mr. John Gjers, and subsequently passed into the hands of the late Mr. Edward Williams. They comprise six blast-furnaces, 78½ feet high by 21 to 22 feet diameter at the bosh. The three furnace-hoists are on Gjers' pneumatic principle (page 342). Blast is supplied up to a pressure of 6 lbs. per square inch by seven blowing engines of the vertical non-condensing kind usual in the Cleveland district. Steam at a pressure of 53 lbs. per square inch is generated in seven Lancashire boilers, 30 feet long by 7½ feet diameter, and fifteen plain cylindrical boilers, 60 feet long by 4 feet diameter. The blast is heated by Cowper stoves. Behind the furnaces is a row of calcining kilns and mineral bunkers, surmounted by a gantry 50 feet high by 600 feet long. Loaded trucks are raised at one end and empties lowered at the other, by means of a pneumatic hoist and drop, similar to those in use at the Ayresome Iron Works. The iron is removed from the six pig-beds and loaded direct into trucks by means of a rope-driven travelling crane, which can reach every part of the pig-beds. The slag is removed by Truran's and Hawdon's machines, and is subsequently deposited out at sea by hopper barges. The works are connected by sidings with the North Eastern Railway, and include a wharf on the river Tees, where ore is imported and pig-iron shipped. Both hematite and Cleveland pig-iron are produced.

THE TEES SIDE IRON AND ENGINE WORKS CO., MIDDLESBROUGH.

The Tees Side Iron Works, situated at J, Plate 55, were established in 1857 by Messrs. Snowdon and Hopkins. They comprised two small furnaces, as well as bar and rail mills. In 1865 the firm amalgamated with Messrs. Gilkes, Wilson and Co., engineers, and was thenceforth styled Messrs. Hopkins, Gilkes and Co. In 1867 the original blast-furnaces were rebuilt, and two new ones were added. The present furnaces are 75 feet high by 24 feet diameter at the bosh. The hoists are two in number, and constructed on Gjers' pneumatic principle (page 342). Blast is supplied by five vertical non-condensing engines, two with 48-inch steam and 100-inch air cylinders, and three with 36-inch steam and 72-inch air cylinders. Steam at a pressure of 55 lbs. per square inch is generated in fourteen plain cylindrical boilers of various lengths and diameters, heated by the furnace gases. The blast is raised to a temperature of 1,500° Fahr. in Cowper stoves, of which there are nine, 60 feet high by 20 feet diameter. Behind the furnaces is a row of nine calcining kilns with mineral bunkers, surmounted by a gantry. To this the full trucks are raised, and from it the empties are lowered, by a pneumatic hoist and drop. The slag is loaded into trucks as shingle by Hawdon's machine, and is subsequently sent out to sea. Cleveland and hematite pig-iron is here made.

With the blast furnaces are associated the extensive Tees Side Engine Works in Lower Commercial Street and Grey Street, covering some 6½ acres at O, Plate 55. The nucleus of this engineering establishment was founded in 1844; and in 1880 it became included in the present Tees Side Iron and Engine Works Co. The works embrace two large foundries, together capable of producing 500 tons of castings per week. They are laid out with every appliance of the most recent and approved kind for the production of castings of the heaviest description, whether for engines of colossal make or for mill and forge purposes. A speciality is made of cylinders for bridge piers, and every class of casting for general builders, such as columns, girders, and stanchions, now so extensively used. The stoves for drying cores are heated by gas in the most efficient and economical manner. A large bridge-building yard is attached to these works, replete with every description of labour-saving machinery; and extensive contracts have been carried out for railways both at home and abroad. Two bridges of great magnitude which were built here are that over the Nerbudda River for the Bombay, Baroda, and Central India Railway, and a bridge of many spans for the Madras Railway. The engineering and fitting shops are of considerable size, and have attached to them smiths' shops and a forge, with all appliances for the preparation of bolts and nuts, rivets &c., on an extensive scale. The shops have turned out many works of considerable magnitude, embracing the entire plant for the Leang Hoo Iron and Steel Works, in China, which comprised blast-furnaces with all the necessary accessories for making pig-iron, as well as rolling mills for making both steel and iron rails and bar iron, and complete appliances for the Bessemer and Siemens-Martin processes. Blowing engines are here made up to cylinders of 100 inches diameter, to produce blast having a pressure of 8 to 10 lbs. per square inch; and also every requirement for either gas or water works.

The company possess a ship yard at K, Plate 55, covering about six acres, and capable of building six vessels at a time, the largest 600 feet in length; it is furnished with all the requisite appliances. They have also a wharf at N.

MESSRS. WILSONS, PEASE AND CO.,
TEES IRON WORKS, MIDDLESBROUGH.

These works, which are situated at P, Plate 55, close to Cargo Fleet railway station, are divided into two portions: namely the eastern or old side, comprising three blast-furnaces; and the western or new side, comprising two additional furnaces. Those on the old side are 75 feet high by 22 ft. 8 ins. to 24 feet diameter at the bosh, and 8 feet to 8 ft. 6 ins. at the hearth; those on the new side are 85 feet high by 27 feet diameter at the bosh, and 9 feet at the hearth. Each group is provided with a hoist driven by a winding engine. Blast is supplied on the old side by a horizontal non-condensing blowing engine, with 108-inch air cylinder by 9 feet stroke, and by three smaller engines; and on the new side by two vertical non-condensing engines made by the Tees Side Iron and Engine Works Co., with 44-inch steam and 100-inch air cylinder by 54 inches stroke. The blast is heated to a temperature of 1,500° Fahr. by twelve Cowper stoves, seven of which, 55 feet high by 22 feet diameter, are on the old side, and five, 55 feet high by 24 feet diameter, are on the new side. Steam at a pressure of 60 lbs. per square inch is generated in sixteen elephant boilers, 42 feet long by 4 ft. 6 ins. diameter, of which eight are on the old side, and eight on the new; the former are supplemented by two plain cylindrical boilers, 60 feet long by 4 ft. 6 ins. diameter. There are seven calcining kilns on the old side and six on the new, all of which are 42 feet high by 24 to 25 feet diameter. In each case the kilns are filled from a gantry, to which loaded trucks are raised by an incline on the old side, and by a direct-acting steam-ram on the new side. The product is solely Cleveland pig-iron, and amounts to about 500 tons per furnace per week. The ore is obtained from the mines in the vicinity owned by Messrs. Pease and Partners. Besides the smelting plant, the works comprise extensive foundries, from which railway and tramway chairs, pot sleepers, and other castings are turned out in large quantities.

MESSRS. COCHRANE AND CO.,
ORMESBY IRON WORKS, CARGO FLEET.

At these works, situated at Q, Plate 55, there are four blast-furnaces, with accessories. The dimensions of the furnaces, which comprise the largest in the district, are as follows:—height 90 feet, diameter at the bosh from 23 to 29 feet, diameter at the hearth 10 feet. The output from the three furnaces now at work is altogether 2,350 tons of pig-iron per week, all of which is of Cleveland quality from local ores. Air is supplied to the furnaces by four blowing engines, at a pressure of 6½ lbs. per square inch at the engines. Three of the latter are simple non-condensing, discharging their exhaust steam into a common main. Part of this steam is employed to drive the fourth blowing engine, which is fitted with a surface condenser, the circulating water being drawn from the river. What remains of the steam is used in evaporators and feed-heaters, and is finally returned to the boilers as feed-water. The evaporators make up for loss of feed-water arising from waste due to steam used for driving hoist-engine and slag-belt engine, blow-off from safety valves, and sludging from boilers and heaters. Steam at a pressure of 50 to 60 lbs. per square inch is supplied by twelve Roots boilers, heated by the furnace gases. The blast is raised to a temperature of 1,500° Fahr. by Cowper stoves, of which there are three to each furnace, each 50 feet high by 26 feet diameter. Of the two furnace-hoists one is a counterbalance water-hoist, and the other is worked by a winding engine placed above the floor level. Behind the furnaces are situated a row of calcining kilns and coke bunkers, to which access is obtained from above by means of a gantry. Loaded trucks are raised at one end by an inclined plane, and lowered at the other end by a brake drop. The works throughout are lighted by electricity, both arc and incandescent lamps being used. The motive power is obtained from a single Parsons steam-turbine running at 8,000 revolutions per minute.

THE NORMANBY IRON WORKS, MIDDLESBROUGH.

These works are situated at R, Plate 55, a little to the east of the Cargo Fleet railway station. They were built in 1859 by Messrs. Jones, Dunning and Co., and were acquired by the present owners about two and a half years ago. They comprise three blast-furnaces, 75 feet high by 17 to 18 feet diameter at the bosh and 7 ft. 6 ins. at the hearth. The furnace hoist is driven by a winding engine, and has been lately erected to replace the original one, which consisted of a 22-inch direct-acting steam ram. Blast at a pressure of 5 lbs. per square inch is supplied to the furnaces by four blowing engines, all of the vertical simple non-condensing type. Of these two have 23-inch steam and 60-inch air cylinders by 36 inches stroke; one has a 32-inch steam and 72-inch air cylinder by 48 inches stroke; and one, which is kept in reserve, has a 23-inch steam and 60-inch air cylinder by 42 inches stroke. In the last engine the ingress and egress of the air are regulated by a slide-valve in the form of a circular casing moving outside the air cylinder and actuated by eccentrics.

The blast is heated by six Cowper stoves, 60 feet high by 21 to 22 feet diameter, two to each furnace. Steam at a pressure of 60 lbs. per square inch is generated in fourteen plain cylindrical boilers 50 feet long by 4 feet diameter, and two Lancashire boilers 30 feet long by 7½ feet diameter, all being heated by furnace gas. These two are provided with fire-brick combustion-chambers, which when heated are able to re-light the gas, when the flame has been momentarily extinguished during the charging of the furnace. Behind the furnaces there is a row of calcining kilns and mineral bunkers. Above is a gantry, to which full trucks are raised by a 36-inch direct-acting steam hoist, and from which the empties are lowered by a balanced drop. The works are lighted throughout by electricity; the installation comprises seven arc-lamps and eighty incandescent, supplied by a continuous-current dynamo made by Messrs. Scott and Mountain, which is driven through a cotton and leather belt by a vertical engine having a single cylinder 7½ × 10 inches. The output of each furnace is about 600 tons per week of hematite pig-iron made from Spanish ore. The ore is unloaded and the pig-iron shipped at a wharf on the river Tees, belonging to the firm and provided with three steam-cranes of 7, 5, and 3 tons capacity. Another wharf is used for loading slag into hopper barges, to be deposited out at sea.

THE CARGO FLEET IRON WORKS, MIDDLESBROUGH.

These works are situated at T, Plate 55, about half a mile to the east of Cargo Fleet station, on the Middlesbrough and Redcar branch of the North Eastern Railway. They were built in 1866 by Messrs. Swan, Coates and Co., which firm was converted in 1879 into the Cargo Fleet Iron Co., and in 1883 into a limited company with Mr. J. G. Swan as managing director. They comprise five blast-furnaces, of which two are 75 feet high by 20 feet diameter at the bosh and 8 ft. 6 ins. at the hearth, and three are 75 feet high by 24 feet diameter at the bosh and 9 feet at the hearth. One of the larger furnaces is at present out of blast. Air at a pressure of 5 lbs. per square inch is supplied by four blowing engines: namely two vertical non-condensing by Messrs. Coulthard of Blackburn, with 35-inch steam and 78-inch air cylinder by 4 feet stroke; one of like construction by Messrs. Cochrane, Grove and Co., with 40-inch steam and 96-inch air cylinder by 4 feet stroke; and one jet-condensing beam-engine by Messrs. Hawks, Crawshay and Co., with 40-inch steam and 100-inch air cylinder by 9 feet stroke. There is also in reserve a vertical engine by Messrs. Kitson and Co., with 42-inch steam and 84-inch air cylinder by 5 feet stroke, fitted with a Morton ejector condenser from which a vacuum of about 20 inches of mercury is obtained. The blast is heated to a temperature of about 1,500° Fahr. by ten Cowper stoves, that is two to each furnace; all of these are 55 feet high by 21 feet diameter. For the easy removal of dust, each stove is provided with a hopper bottom, communicating by way of a trap door with a tunnel, which is accessible to barrows on the floor level. Steam at a pressure of 55 lbs. per square inch is generated in fifteen plain cylindrical boilers, 75 feet long by 4 ft. 6 ins. diameter, and five of 60 feet length by 5 ft. 6 ins. diameter, all being heated by the furnace gases. The furnace hoists are two in number of the water-balance kind. Behind the furnaces is a row of ten calcining kilns, each 35 feet high by 21 feet diameter; the gantry surmounting them is approached by an incline, up which the loaded trucks are pushed by locomotives, the empties afterwards descending by the same route. The output of the four furnaces now in operation is about 2,000 tons per week of Cleveland pig-iron. The ore is obtained from the company's mines at Normanby, Liverton, and Waterfall; and the flux from their Mickleton limestone quarries. At the Liverton mine the ironstone is calcined before being sent away to the furnaces; for this purpose a plant has been erected comprising seven kilns with the necessary gantry and hoists. The company own a wharf on the river Tees, having a frontage of 215 feet. Of the total quantity of slag produced, three-fourths is tipped upon the land adjoining the works, and one-fourth is converted into slag blocks by the Tees Scoriæ Brick Co.

THE TEES SCORIAE BRICK CO., AT CARGO FLEET IRON WORKS, MIDDLESBROUGH.

The manufacture carried on at these works is that of slag blocks for paving. The plant comprises one rotating wheel, fitted with 140 moulds; and also eighteen kilns, each capable of holding 1,000 blocks. From twenty to thirty different sizes of blocks are made. By arrangement with the Cargo Fleet Iron Co. these works are carried on at U, Plate 55, within the boundary of the Cargo Fleet Iron Works.

THE CLAY LANE IRON WORKS, SOUTH BANK.

These works are situated at V, Plate 55, about half a mile to the east of South Bank station on the Middlesbrough and Redcar branch of the North Eastern Railway. They were built in 1859 by Messrs. Elwon, Malcolm and Co., and comprised three blast-furnaces until 1863, when three more were added; they subsequently became the property of Messrs. Thomas Vaughan and Co., and are now owned by the

Clay Lane Iron Co. The works cover an area of 21 acres and include six furnaces: namely three 85 feet high by 25 feet diameter at the bosh and 9 feet at the hearth, of which two are being relined; one 85 feet by 25 feet and 9 ft. 6 ins., which has lately been remodelled; and two 85 feet by 20 feet and 8 feet. Air is supplied to the furnaces by three beam and three vertical non-condensing blowing engines. Of the beam engines two have 40-inch steam and 100-inch air cylinders by 8 feet stroke, and one has 38-inch steam and 84-inch air cylinder by 7 feet stroke; one only is in regular use. Of the vertical engines one has 45-inch steam and 100-inch air cylinder by 54 inches stroke; and two, which are quite new, have 48-inch steam and 100-inch air cylinders by 54 inches stroke. The blast is raised to a temperature of 1,500° Fahr. by Cowper stoves, of which there are thirteen, 55 feet high by 19 to 21 feet diameter; two of them have external combustion chambers 9 ft. 6 ins. diameter. The furnace hoists are three in number, one being of the water-balance type, and two driven by winding engines. Behind the furnaces is a row of mineral bunkers, surmounted by a gantry which is reached by an incline of 1 in 25. The loaded trucks are pushed up by a locomotive; the empties descend by the same route. Behind the mineral bunkers is a row of ten kilns, 47 feet high by 24 to 29 feet diameter; one of them is elliptical in section, which is said to effect a saving in coal. The kilns are charged from another gantry, to which the trucks are hauled up an incline of 1 in 4 by a winding engine; the empties are lowered at the other end by a balanced drop controlled by a brake. Steam is raised for the blowing and other engines by sixteen boilers, all heated by the furnace gases: namely ten three-flue Beeley boilers, 30 feet long by 8 feet diameter; three Lancashire boilers, 30 feet long by 7 feet diameter; and three plain cylindrical, from 70 to 75 feet long and 4 feet 6 inches diameter. The feed is heated to 200° Fahr. by the exhaust steam from the blowing engines. The output of the larger furnaces is 600 tons of pig-iron per week, and of the smaller 450 tons. Cleveland ironstone only is smelted, which is obtained mostly from the company's South Skelton mine. The works include a jetty on the river Tees for shipping the pig-iron, nearly all of which is exported.

MESSRS. BOLCKOW, VAUGHAN AND CO., CLEVELAND STEEL AND IRON WORKS, SOUTH BANK.

Cleveland Iron Works.—These works are situated at W, Plate 55, on the south side of the Saltburn branch of the North Eastern Railway, between South Bank and Eston Grange stations. They comprise eight blast-furnaces, Plate 56, of which Nos. 1, 2, and 3, forming the eastern group are now out of blast. When they were stopped a year or two ago, they had been at work for over twenty years without being re-lined. Nos. 4 to 8, which form the western group, are 92 to $95\frac{1}{2}$ feet high, by 20 feet to 25 ft. 8 ins. diameter in the bosh, and 9 to 10 feet in the hearth. Blast at a pressure of $5\frac{1}{4}$ lbs. per square inch is delivered to them from the same mains which also supply the three hematite blast-furnaces that make for the acid converters. The blowing engines for these two groups of furnaces are eight in number, having 40-inch steam cylinders with 96 inches stroke. The blast is heated to a temperature of about 1,500° Fahr. by twelve Cowper stoves, 60 feet high by 25 feet diameter. There are two hoists worked by water-balance. Steam for the blowing engines is generated in twenty-eight Lancashire boilers, 30 ft. 4 ins. long by 7 feet diameter, and eleven plain cylindrical boilers, 75 feet long by 5 feet diameter. Behind the blast-furnaces is a row of mineral bunkers, and another of fourteen calcining kilns 50 feet high. Both bunkers and kilns are surmounted by gantries to which access for railway trucks is gained by inclines. The output of these works averages over 600 tons of Cleveland pig-iron per furnace per week. The ironstone is obtained from the company's mines at Eston. The slag is tipped upon the foreshore of the river. The works are lighted by electricity, for which the current is generated at the central station in the steel works.

Hematite Blast-Furnaces.—Adjoining the steel works on the south are the hematite blast-furnaces, Plate 56, in which hematite pig-iron is produced for use in the acid-lined converters. The bulk of the ore which is used is that known as Rubio, and is obtained from mines in the north of Spain. The company are largely interested in the Luchana Co.'s mines at Bilbao, from which also a portion of their supplies are drawn. There are three blast-furnaces, 72 feet high, 23 to 24 feet diameter at the bosh, and 10 feet in the hearth. Blast at a pressure of $5\frac{1}{4}$ lbs. per square inch is taken from the same mains, which also supply the Cleveland Iron Works close by. Eight non-condensing beam engines supply blast to these two sets of furnaces. They have cylinders 40 inches diameter and 96 inches stroke. The blast is heated to a temperature of about 1,450° Fahr. in eight Cowper stoves, 60 feet high by 25 feet diameter. There are two hoists, one water-balance and the other actuated by a winding engine. Behind the furnaces is a row of thirty-two mineral bunkers surmounted by a gantry, which is approached by an incline. The output of these furnaces is about 1,000 tons of hematite pig-iron per furnace per week; as much as 1,080 tons has been produced.

Cleveland Steel Works.—The steel works, Plate 56, including the hematite furnaces, were erected in 1876 to the designs and under the supervision of Mr. E. Windsor Richards, for the manufacture of steel rails by the Bessemer process. Since then they have been much extended, and plant for the basic and open-hearth processes has been added. The works now occupy an area of sixty acres, of which twenty are covered with roofing. When in full operation they are capable of producing 5,500 tons of finished steel per week, and afford employment to 2,500 men.

On approaching the main building from the west, the recently erected mixing plant for the de-sulphurization and homogenization of pig-iron by the Massenez process is first passed; it comprises two mixers, each capable of holding 140 tons of molten pig-iron. They are mounted on trunnions and manipulated by hydraulic rams. The molten metal is brought by locomotives from the blast-furnaces in bogie ladles, and raised by an incline to the level of the gantry on which the mixers are placed. The metal is poured in at one end of the mixer, and run out at the other end as required by the converters.

At the west end of the main building are the Bessemer and basic shops. The Bessemer shop contains four 8-ton acid-lined converters, served by two centre cranes and six ingot cranes. The cranes and converters are actuated by hydraulic power. On the converter gantry are four small spiegel cupolas, served by a hydraulic lift. Another lift is employed to raise the molten metal to the gantry level. There are also cupolas for melting pig-iron when required.

The basic shop contains six 15-ton basic-lined converters, served by four centre cranes and eight ingot cranes, all worked by hydraulic power. The converters are tipped by worm gearing driven by steam engines. On the converter gantry are six spiegel cupolas with two hydraulic lifts. The molten metal is raised to the gantry level by a hydraulic hoist, which by spiral guides is made to turn through a right angle during its ascent; this avoids the necessity for a turntable. A 30-ton overhead travelling crane commands all parts of the basic shop.

Behind the two groups of converters are the "plug" shops where the linings are prepared. They contain sixteen drying stoves, five pug-mills, one stone-breaker, five cupolas for shrinking dolomite for basic linings, and one steam-hammer for consolidating the perforated plugs. These shops are served by two 25-ton overhead travelling cranes. A special underground railway with frequent openings affords a ready exit for slag and refuse of all kinds.

The blowing engines and pumps are situated in a large building at the southern end of the Bessemer shop. There are four double blowing engines with 40-inch steam and 50-inch air cylinders by 60 inches stroke, of which three are by Messrs. D. Adamson and Co., and one is by Messrs. Bolckow, Vaughan and Co. There are five pairs of horizontal hydraulic pumps, with 18 × 24-inch cylinders and 6-inch plungers. The accumulators, of which there are two, have 18-inch rams, and are loaded to a pressure of 600 lbs. per square inch. In the same building are situated cupola blowers, pumps, and a feed heater.

Proceeding in an easterly direction to the mills, the ingot-heating furnaces are next passed, of which seven are horizontal and six vertical. All are on the regenerative principle and heated by producer gas. The ingots are charged and drawn by hydraulic power in the horizontal furnaces, and by steam overhead travelling cranes in the vertical ones. Producer gas is supplied by producers of the Siemens type.

The cogging mill consists of a stand of 48-inch rolls, fitted with hydraulic screwing-gear, and provided with live rollers and tilting gear. It is driven by a pair of horizontal reversing engines, made by Messrs. Davy Brothers, having 40-inch cylinders by 60 inches stroke, and geared in the proportion of 2 to 1.

The plate mill is in line with the cogging mill, and consists of two stands of rolls 36 inches diameter by 9 feet long. It is provided with a traversing table of live rollers on each side, and is driven by a pair of horizontal reversing engines, made by Messrs. Thwaites and Carbutt, having 36-inch cylinders, and geared in the proportion of 3 to 1. One of the plate shears, which is said to be the largest in the world, was made by Messrs. Bolckow, Vaughan and Co. at their Middlesbrough Engineering Works, and is capable of cutting cold steel plates up to 2½ inches thick. The blades are 12 feet long with 4 ft. 8 ins. gap, the standards being 9 feet apart. The shears are driven by a single 26-inch cylinder through helical gearing.

The plate cogging mill, to the north of the 48-inch cogging mill, consists of a single pair of 60-inch rolls, and is provided with steam screwing-gear, live rollers, and Richards tilting gear. The engines, made by Messrs. Galloway, are horizontal reversing, having two 40-inch cylinders, and geared in the ratio of 2 to 1. Each of the two cogging mills is provided with a pair of horizontal hot-bloom shears, made by Messrs. Davy Brothers, capable of cutting 250 square inches in section.

No. 1 mill is capable of producing 500 tons of rails of heavy section per shift. It comprises two stands of 30-inch rolls, one provided with live rollers and the other with loose rollers. The roughing rolls are driven direct by a pair of horizontal reversing engines made by Messrs. Tannett, Walker and Co., having 54-inch cylinders with 72 inches stroke. The finishing rolls are directly connected with a pair of horizontal reversing engines made by Messrs. Davy Brothers, having 48-inch cylinders with 60 inches stroke.

No. 2 mill is used for the production of sleepers, angles, and rails. It comprises two stands of 26-inch rolls, and is in connection with the engines which drive the roughing rolls of No. 1 mill.

No. 3 mill is capable of producing 1,500 tons of angles or light rails per week. It comprises two stands of 30-inch rolls, and is driven direct by a pair of horizontal reversing engines made by Messrs. Tannett, Walker and Co., having 60-inch cylinders with 60 inches stroke.

No. 4 mill is capable of producing 250 tons of fish plates or merchant bars per week. It comprises three stands of 16-inch rolls, and is driven direct by a pair of horizontal reversing engines having 32-inch cylinders with 52 inches stroke. In connection with this mill there is a blooming mill driven by the same pair of engines through gearing in the proportion of $2\frac{1}{4}$ to 1.

All the above mills are provided with suitable shears and saws. There are in all eight re-heating furnaces, namely four for the plate mill and four for the various rail and bar mills. Nos. 1, 2, and 3 mills are assisted by a 25-ton overhead travelling crane for changing the rolls. The same crane has access to the roll-turning shop. The rail bank is under a commodious roof, and is supplied with the usual straightening, drilling, and knifing machinery, and inspection benches. Close by is the testing house, containing a 100-ton Buckton and an Adamson testing machine.

The steel-melting furnaces are seven in number, and are all acid lined. Two are of the original Siemens type, and have a capacity of 12 tons each. Five have iron-cased regenerators, two being of 20 and three of 30 tons capacity. In front of the latter is the casting pit, in which ingots up to 5 tons in weight are cast. At the east end of the range of melting furnaces is a steel foundry, having a 25-ton overhead crane and two drying stoves. Steel castings up to 10 cwts. in weight are here made for use in the works.

Steam is supplied for general use at a pressure of 80 lbs. per square inch by Lancashire boilers 30 feet long and 7 feet diameter. A railway of 3 feet gauge permeates the entire steel works, in addition to the ordinary-gauge sidings. The steel works as well as the adjoining Cleveland and South Bank blast-furnaces are lighted by electricity, both arc and incandescent lights being used. The generating station comprises eleven continuous-current dynamos driven by a pair of horizontal engines, one single-cylinder horizontal engine, and one Brotherhood three-cylinder engine.

MESSRS. BOLCKOW, VAUGHAN AND CO., SOUTH BANK IRON WORKS, SOUTH BANK.

These works are situated at X, Plate 55, on the north side of the Saltburn branch of the North Eastern Railway, and immediately opposite the Cleveland Iron Works, Plate 56. They comprise eight blast-furnaces, 78 to 79 feet high by 19 to 23 feet diameter in the bosh, and 9 to 10 feet in the hearth. Blast is supplied by seven blowing engines, of which three are of the beam, three of the horizontal, and one of the vertical kind ; none of them are compound and none are condensing. The air is heated by fifteen Cowper stoves, 64 feet high by 25 feet diameter. Steam is generated in fourteen Lancashire and twelve plain cylindrical boilers. There are two water-balance hoists, and one worked by a winding engine. Behind the furnaces is a row of nineteen calcining kilns built of brick, and behind these a range of mineral bunkers. All are surmounted by gantries and approached by inclines. The output of the works is about 600 tons of Cleveland pig-iron per furnace per week, the ore being obtained from the company's mines at Eston. The works are lighted by electricity throughout. The slag from these, as well as from the other furnaces, is tipped upon the foreshore of the river Tees, where the company own 113 acres of land. For the Cleveland Steel Works, and the Cleveland and the South Bank Iron Works, raw materials are imported and finished products shipped at a wharf upon the river Tees with 801 feet of frontage, 50 feet wide, and provided with five 5-ton and three 35-cwt. cranes. The wharf is approached from the South Bank works by a jetty about 2,000 feet long.

MESSRS. BELL BROTHERS, CLARENCE IRON WORKS, PORT CLARENCE.

These works are situated at Y, Plate 55, on the north or Durham side of the river Tees. They are connected with the Port Clarence branch of the North Eastern Railway; and are also reached from Middlesbrough by the Corporation steam ferry. They are divided into two parts, namely the "old side" with eight blast-furnaces, and the "new side" with four.

The Old Side was erected in 1853 by Sir Lowthian Bell and his brothers, Messrs. Thomas and John Bell. The eight furnaces are 80 feet high, by 17 to 25 feet diameter at the bosh, and 8 feet at the hearth. There are six hoists, worked by hydraulic rams acting on ropes and pulleys. The speed of the ram is multiplied ten times. Blast at a pressure of 5¾ lbs. per square inch is supplied to the furnaces by five vertical simple non-condensing engines, of which two, having 36-inch steam and 100-inch air cylinders with 54 inches stroke, were built by Messrs. Cochrane, Grove and Co., and three, having 42-inch steam and 100-inch air cylinders with 60 inches stroke, by Messrs. Kitson and Co. Steam is supplied at a pressure of 90 lbs. per square inch by sixteen three-flue Beeley boilers, each being 30 feet long by 8 feet diameter. These are arranged in two rows, and are heated by the furnace gases; in case of necessity they can be fired by hand. They are fed by injectors worked by the exhaust steam from the blowing engines. The blast is heated to a temperature of about 1,400° Fahr. by eighteen Cowper stoves, each being 61 feet high and 21 feet diameter. Behind the furnaces is a row of fifteen kilns for calcining the Cleveland ore, which is exclusively used, and is obtained from the firm's own mines near Saltburn. The loaded trucks reach the top of the gantry by a long incline, and subsequently descend the same way. Behind and parallel to the calcining kilns is a row of bunkers surmounted by a gantry, to which access is obtained by the same incline.

The New Side was erected in 1873, and the four blast-furnaces are each 80 feet high, by 23 feet diameter at the bosh, and 8 feet at the hearth. The furnace hoists are on the hydraulic principle, as already described. The three blowing engines are by Messrs. Hopkins, Gilkes and Co., and have 48-inch steam and 100-inch air cylinders with 54 inches stroke. The exhaust steam passes through a heater, where it raises the temperature of the feed-water to 212° Fahr. Steam is supplied at a pressure of 50 lbs. per square inch by nineteen plain cylindrical boilers, 4½ feet diameter, of which fourteen are 80 feet long, and five are 60 feet. All are heated by the furnace gases. The blast is heated by ten Cowper stoves. Behind the furnaces is a row of calcining kilns and bunkers, the gantry being approached by an incline. The hydraulic plant for working the furnace hoists consists of five double hydraulic pumps with 16 by 17¾ inches steam cylinder and 3½-inch rams, working in connection with an accumulator having a 17-inch ram loaded to give a pressure of 800 lbs. per square inch. There are seven Cameron pumps for pumping tuyere and other water. The average output per furnace per week is 500 tons of Cleveland pig-iron. The Le Chatelier electric pyrometer is now in regular use at these works. By means thereof the temperature of the blast or of the gases in the downcomer of any furnace can be readily ascertained. An autographic recording instrument, the invention of Professor Roberts-Austen (Proceedings 1891, page 551), has lately been brought into use in connection therewith.

THE SALT UNION,

PORT CLARENCE SALT WORKS, PORT CLARENCE.

These works contain two sets of evaporating pans, one to the west and the other to the east of Messrs. Bell Brothers' Iron Works. The western set at Z, Plate 55, comprises fifteen pans, each 60 feet long by 24 feet broad and about 1 ft. 9 ins. deep; they are heated by coal fires. Close at hand is a filter bed, into which the brine is pumped direct from the bore-holes about a mile distant. After being filtered the brine passes into a storage reservoir, and is thence forced by a Worthington pump into a tank, whence it flows down by gravity into the evaporating pans as required. The eastern set comprises four pans, which are heated by the waste gases from Messrs. Bell Brothers' blast-furnaces on their way to the chimney and after they have passed under the boilers. The total number of bore-holes in connection with these salt works is eight.

MESSRS. WILLIAM WHITWELL AND CO., THORNABY IRON WORKS, THORNABY-ON-TEES.

These works, situated at A, Plate 57, are divided into two departments, namely the blast-furnaces and the finished-iron works.

The blast-furnaces are three in number, each 80 feet high by 19 to 22 feet diameter at the boshes. They were built in 1873 to replace three others erected in 1859. Air is supplied to the furnaces by four blowing engines: namely two simple non-condensing by Messrs. D. Adamson and Co., having 47-inch steam and 100-inch air cylinder with 60 inches stroke; one simple jet-condensing engine by Messrs. Galloway and Sons, having 50-inch steam and 100-inch air cylinder with 60 inches stroke; and one simple non-condensing engine by the Tees Side Iron and Engine Works Co., having 48-inch steam and 100-inch air cylinder with 54 inches stroke. The blast is heated to a temperature of 1,450° Fahr. by Whitwell stoves, of which there are fourteen in all. Of these the newer and larger ones are 65 feet high and 22 feet diameter. The weekly output of the three furnaces together is about 2,500 to 2,600 tons of pig-iron, all hematite. The ores are obtained from Gellivara, Elba, Algeria, South Spain, and Bilbao, and need no calcination.

The finished-iron works were erected in 1866, and have since been much extended. The manufacture here carried on is that of wrought-iron bars of various sizes and sections, including cables for Admiralty and merchant service, tee, angle, channel, hoop, round, square, bevel, flat, and many others. The output of finished iron is about 600 to 700 tons per week, a large proportion being for export to foreign countries. The forge contains thirty-three puddling and two ball furnaces; three 3-ton 24-inch cylinder steam-hammers; and an 18-inch and a 22-inch forge train. The 18-inch train comprises four stands of rolls, and is driven by a horizontal engine with cylinder 27 × 48 inches. The 22-inch train comprises two stands of rolls, and is driven by a horizontal engine with two cylinders, 18 and 26½ inches diameter by 48 inches stroke, arranged tandem. Both engines are supplied with steam at 55 lbs. boiler pressure.

The mill department contains six mills, having 24-inch, 15, 10, 9, 8, and 7-inch centres. The new 24-inch mill comprises three stands of rolls, and is driven by a pair of horizontal reversing engines made by Messrs. Davy Brothers, having cylinders 24 × 36 inches. The mill is provided with live rollers driven by an auxiliary engine. There is also a pair of horizontal shears by Messrs. J. Buckton and Co., capable of cutting 49 square inches of sectional area; and a circular saw by Messrs. Kitson and Co. An overhead rope-driven travelling crane capable of lifting 10 tons has access to all parts of the mill, and conveys rolls to or from the roll-turning shop. The mill is served by seven heating furnaces, to each of which a vertical boiler is attached. The 15-inch mill comprises three ordinary stands of rolls, and one for planishing. It is driven direct by a horizontal engine with two cylinders 15 and 22½ inches diameter by 30 inches stroke, arranged and supplied as previously described in the case of the 22-inch forge train. Attached to this mill are two circular saws by Messrs. Davy Brothers. The 10-inch and 9-inch mills are each driven by a vertical engine having a cylinder 24 × 30 inches, by Messrs. Perry and Co. Each mill comprises four stands of rolls. The 8-inch mill is driven by a vertical engine with cylinder 18 × 30 inches by Messrs. Perry and Co., and comprises five stands of rolls. The 7-inch mill is driven through a belt by a vertical engine with cylinder 21½ × 26 inches, controlled by Schaeffer and Budenberg's variable-expansion gear; it comprises four stands of rolls. There is also a strip mill with a pair of 14-inch planishing rolls, driven by a horizontal engine with cylinder 21 × 30 inches. The total number of heating furnaces in all the mills is eighteen. Steam is supplied for the various steam engines at a pressure of 55 lbs. per square inch by 47 boilers, of which 4 are Cornish hand-fired boilers, 28 feet long by 6 feet diameter, and 43 are heated by waste gases from the puddling and heating furnaces; and of these 29 are vertical, 4 are horizontal with two flues, and 10 are of the elbow horizontal kind with central flue. In connection with the finished-iron works there are the usual fitting and roll-turning shops, pumping house, locomotive shed, and testing houses. The latter contain a fine 100-ton testing machine by Messrs. J. Buckton and

Co., driven by a gas engine of 5 horse-power nominal; and a horizontal 100-ton testing machine by Messrs. Daniel Adamson and Co. The works include also a convenient wharf on the river Tees, 600 feet long, provided with six 3-ton cranes; here ore is unloaded, and pig-iron and bar-iron shipped.

MR. R. W. CROSTHWAITE,
UNION FOUNDRY, THORNABY-ON-TEES.

These works had their origin at Falkirk, where they were founded by Mr. R. W. Crosthwaite in 1849. In 1878 they were removed to their present site in Thornaby at B, Plate 57. The works are now owned and managed by Messrs. J. R. Crosthwaite and J. P. Fry. The manufacture carried on is that of light castings of all kinds used by builders. They include rain-water pipes and gutters, baths, kitchen boilers, registers and stoves, stable fittings, &c. There are two moulding shops: a larger one in which light castings are made, covering an area of over an acre; and a smaller one provided with two cranes, for heavier work; one cupola, 4½ feet diameter and capable of melting 6 tons per hour, is sufficient for both shops. No. 3 Cleveland pig-iron is used, mixed with one-third of its weight of scrap castings. Blast is supplied by a Baker blower. The cupola-hoist is worked by an inverted direct-acting steam cylinder 8 inches diameter. The molten iron is run from the cupola into bogie-ladles, which are taken on railways to various parts of the shops, and from them small hand-ladles are fed. The castings after leaving the moulding department pass through the fettling shop where they are cleaned, and the passing shop where they are examined by the inspector. The finer work is then taken to the grinding shop, which is provided with nine grindstones, and four sets of emery glazers. After being pickled in sulphuric acid to remove the surface skin, all ornamental castings, such as stoves and registers, are ground and polished, in order to prepare them for being subsequently japanned and polished. The fitting shop, where the various parts of stoves are fitted together, contains drilling machines, vices, emery grinders, &c. There is a large store-room where finished products are kept, and a show-room. All the machinery is driven by a horizontal engine, having a cylinder 16 inches diameter by 36 inches stroke. Steam at a pressure of 80 lbs. per square inch is supplied by a Cornish boiler 20 feet long by 6 feet diameter. On account of the large quantity of repetition, iron patterns are almost exclusively used. In the execution of highly ornamental work the design is first perfected in clay, and from this a wax cast is taken, which in turn is used as a pattern for a casting made of a mixture of lead and tin. From this, after it has been carefully finished, casts in iron are taken, each of which serves as a pattern. Besides the department already mentioned, there is a pattern shop and store, a japanning shop containing stoves, a graining shop where cast-iron is grained to imitate oak or marble, and a tile room where the tile work of the registers is put together. The speciality of the works is a register with semi-slow combustion grate, sloping fire-brick back, and adjustable canopy for the escape of waste gases. About 200 of these are made per week. The total output from the works is about 100 tons of castings per week, and the number of men employed is about 300.

MESSRS. HEAD, WRIGHTSON AND CO., TEESDALE IRON WORKS, THORNABY-ON-TEES.

These works are situated in Thornaby at C, Plate 57, between the river Tees and the Darlington section of the North Eastern Railway. They were established in 1856 by Messrs. T. H. Head and J. Wright. Ten years later they were acquired by Messrs. C. A. Head and T. Wrightson, by whom in 1890 they were converted into a company, with Mr. C. A. Head as chairman and Mr. William Anderson as managing director. The manufacture carried on is that of bridges, piers, roofs, castings, and general engineering work. Numerous railway, canal, and road bridges have been constructed here for various parts of Great Britain, India, Egypt, China, Japan, the Cape of Good Hope, Spain, Mexico, New Zealand, and other countries. The works occupy 15 acres of land, and include an extensive wharf on the river Tees. The bridge yard is equipped with an efficient system of overhead cranes. Both pneumatic and hydraulic riveters are employed, the former being preferred. Holes are drilled wherever possible; but, if punching is resorted to, they are subsequently rimered out. In course of construction were seen several bridges for China, India, and the Colonies, and a large quantity of blast-furnace and other work. Also somewhat of a novelty in the shape of a large quarantine hospital, floated on ten pontoons which form a platform of about 140 × 90 feet. This structure is to be moored at the mouth of the Tees (page 325), for the reception of patients suffering from any infection which might be brought in by the large number of ships visiting the port; it is ordered by the Tees Port Sanitary Authority, the engineer being Mr. William George Laws, engineer to the city of Newcastle-on-Tyne.

Along the eastern boundary is a row of sheds, under which are all the necessary appliances for dealing with plates, angles, and other materials needed for bridge or roof work. They include punching and shearing machines, hydraulic bending presses, saws, grinders, plate-edge planing, drilling, and screwing machines, lathes, riveting machines, bending rolls, and hydraulic apparatus. Near at hand is an extensive smiths' shop, fitted with all usual appliances. The template shed is 51 feet long and 30 feet broad, and is conveniently equipped for laying down the various details full size on the floor.

At the south end of the works is a large brick building, once used as a cotton mill. Its several floors are now made use of as machine, pattern, and fitting shops, stores, etc.

The foundries are six in number, and are arranged along the western boundary. At the southern end is No. 1 foundry, provided with two drying stoves, and a travelling crane of 46 feet span having access to all parts. Outside this foundry there are four cupolas served by one steam-lift. Nos. 2 and 3 foundries are mostly engaged in the manufacture of repetition work, and are provided with light railways for easily handling the moulds. No. 4 foundry is furnished with three cupolas, which are served by one steam-hoist.

Next comes the chair foundry, No. 5, where railway chairs, of which a speciality is made, are cast in large quantities; here are two cupolas served by a pneumatic hoist. No. 6 foundry is comparatively new, and is used for the manufacture of ingot moulds and heavy castings made principally of hematite iron. It is provided with a 10-ton steam travelling crane, two 5-ton swing cranes, and two drying stoves. Outside are two cupolas, with a 12-inch direct-acting steam-lift.

The offices are contained in a handsome and commodious building situated at the entrance to the works. The number of men employed is at present about 1,200.

MESSRS. APPLETON, FRENCH, AND SCRAFTON, CLEVELAND FLOUR MILL, THORNABY-ON-TEES.

This is an imposing brick building situated close to the banks of the river Tees at D, Plate 57. It was built in 1871 by Mr. R. H. Appleton, whose business was amalgamated about three years ago with those of Messrs. T. French and Co. and Messrs. Scrafton Brothers. The main building is divided into two parts, called the north and the south side, each containing a complete set of milling machinery driven by a separate engine. In front of the main building and built upon the wharf is the elevator tower, provided with a trunk which is let down into the hold of a ship and elevates the grain therefrom at the rate of about 30 tons per hour, depositing it direct into the silos and storehouses. The latter occupy an adjoining building to the north of the mill. After undergoing the usual preliminary treatment, by which the wheat is separated from lighter and heavier particles of foreign matter and grain of other kinds, it is crushed by being passed through a succession of rollers, first fluted and then smooth. During its progress it is purified from the husks or bran, and pollard; and finally emerges in the condition of flour, middlings, or semolina. At present the south side is undergoing temporary repairs, and the weekly output is therefore only about 3,500 sacks of flour of 280 lbs. each. The machinery on the north side has recently been renewed, for the most part by

Mr. Henry Simon of Manchester. The north side is driven by two complete compound tandem horizontal engines, working on one shaft with cranks at right angles. In one engine the cylinders are 20 and 28 inches diameter by 42 inches stroke, and in the other 18 and 27 inches diameter by 36 inches stroke. Both the engines are provided with jet condensers. On the crank-shaft is mounted a pulley 18½ feet diameter, which drives the various lines of shafting by means of fifteen hemp ropes. The south side, when at work, is driven by a vertical compound engine of the marine type, having cylinders 19½ and 33 inches diameter by 42 inches stroke, and provided with a jet condenser. Steam at a pressure of 75 lbs. per square inch is supplied by four hand-fired Lancashire boilers, 27 feet long by 7 feet diameter. The mill is fitted throughout with Grinnell's sprinklers, of which this is said to be the largest installation in any flour mill in the world. The total number of men employed is about 100. The company have mills also in Stockton at E, Plate 57, in Middlesbrough at L, Plate 55, in Darlington, and in Bishop Auckland.

MESSRS. CRAIG, TAYLOR AND CO., THORNABY SHIPBUILDING YARD, THORNABY-ON-TEES.

Situated at F, Plate 57, these works were established in 1884, and have already turned out many large vessels. A speciality of late years has been a number of vessels for carrying petroleum-oil in bulk. One of the largest of these was seen just finishing, namely the " St. Helen's," the dimensions of which are as follows :—355 feet length by 45 feet beam and 30 feet depth. She is fitted with engines amidships, which is a novelty first introduced by this firm, the engines of the majority of oil vessels being placed aft; she consequently has a tunnel, which is thoroughly ventilated and provided with special means of entrance and exit; and the thrust seating is in the engine room. All these vessels are fitted with a complete system of electric lighting, steam heating, and steam cooking, on account of the peculiar exigencies of the trade in which they are engaged.

Alongside was a handsome sailing vessel, the "San Ignacio de Loyola," also built for the purpose of carrying oil in bulk. Sailing craft lend themselves to the requirements of this trade with greater facility than steamers. A donkey boiler, Worthington pumps, dynamo, and electric light are also fitted in this vessel.

NORTH SKELTON IRONSTONE MINES.

These mines are on a portion of the Skelton royalty belonging to Mr. J. T. Wharton, and the two shafts were sunk in 1870–73, reaching the ironstone at a depth of 720 feet. The winding shaft is 14 feet diameter. During the sinking, feeders of water were met with, amounting to over 3,000 gallons per minute, which were ultimately tubbed off at a depth of 432 feet.

The winding engine, built by Messrs. Musgrave and Sons of Bolton, has two horizontal cylinders 36 inches diameter with 6 feet stroke. The drum is parallel, 18½ feet diameter. The full load is about 3¾ tons.

The haulage is on the main and tail-rope system, by a 50-horse-power non-condensing compound engine, made by Messrs. Robey and Co. of Lincoln, having high-pressure cylinder 13¼ inches and low-pressure 23 inches diameter with 24 inches stroke, driving four drums for working the east and west sides of the pit; the boiler is multitubular, with 140 lbs. pressure of steam.

The mine is ventilated by a Guibal fan 36 feet diameter by 12 feet wide, producing about 120,000 cubic feet of air per minute.

The pumping engine on the surface, built by Messrs. Andrew Barclay, Son and Co., of Kilmarnock, is condensing, with inverted cylinder 65 inches diameter and 8 feet stroke. The beam extends to both pits, having a 20-inch set of pumps in the bottom of the upcast pit, with 8 feet stroke, which delivers at 504 feet from surface through a connecting drift to a 15-inch set in the winding pit; the latter set is divided into two lifts, and is hung on the other end of the beam.

The whole output is got by Walker's machine drills driven by compressed air. The compressing engine, built by Messrs. John Fowler and Co. of Leeds, is direct-acting, having a steam cylinder 20 inches diameter and an air cylinder 22 inches diameter, both with 60 inches stroke. The steam pressure is 50 lbs. per square inch.

LUMPSEY IRONSTONE MINES.

These mines were sunk in 1878–80 on a portion of the Kilton royalty belonging to Mr. J. T. Wharton. The shafts are 15 feet diameter, and reach the ironstone at a depth of about 600 feet. During the sinking, feeders of water amounting to 1,700 gallons a minute were met with; but these were successfully tubbed off at a depth of 504 feet, a suitable bed for the crib having been found in the Cleveland top seam at the bottom of the lower oolite.

The winding engine, built by Messrs. John Fowler and Co. of Leeds, has two 42-inch horizontal cylinders with 6 feet stroke. The drum is conical, being 17 feet diameter at the smaller end and 21 feet at the larger. A full load is nearly 4 tons of ironstone, and with this load 240 tons have been drawn in an hour.

The system of haulage is that of the endless rope, which is hung on hooks beneath the tubs. Self-acting engaging and disengaging appliances have been adopted.

The mine is ventilated by a fan, 14 feet diameter by 10 feet wide, producing about 90,000 cubic feet of air per minute.

Machine drills worked by hydraulic power and by petroleum engines are in daily operation.

CARLIN HOW IRONSTONE MINES.

These are in the Skinningrove valley upon Mr. J. T. Wharton's Kilton estate. To suit railway requirements the shafts 156 feet deep are upon the rise of the royalty. The pumping is done by ropes. The engines for hauling are upon the surface. The winding is done by a Fowler semi-portable engine. Mechanical drills are worked by electricity (page 309) at about a mile inbye.

LOFTUS IRONSTONE MINES.

These mines are leased to Messrs. Pease and Partners, the principal lessor being the Marquis of Zetland. The bed of ironstone 9 feet in thickness is worked from two drifts; but at the present time one drift only is being worked. The present output of ironstone is about 7,500 tons per week, of which 90 per cent. is won by Walker's pneumatic drilling machines and 10 per cent. by hand labour. The drilling machines are actuated by compressed air at a pressure of 55 lbs. per square inch. The compressor is a single tandem compound engine made by Messrs. J. S. Walker and Brother, Wigan. All the water issuing from the seam at a higher level than the entrance of the mine is conveyed down to the surface by gravitation through the air pipes, as often as is necessary.

THE PORT AND INDUSTRIES OF THE HARTLEPOOLS.

By Mr. THOMAS MUDD, Honorary Local Secretary.

A glance at the map of Hartlepool, Plate 58, will afford a correct idea of the relative geographical positions of the towns of the two Hartlepools. The ancient town of Hartlepool stands on a rocky peninsula to the north of the Hartlepool bay, and has 22,000 inhabitants. The modern town of West Hartlepool lies in the hollow of the bay, and is separated from Hartlepool by a distance of a mile, which is occupied by a wide navigable channel leading to the deep-water entrance of the docks, by the village of Middleton, and by a portion of the docks themselves. West Hartlepool has a population of about 45,000. There is a second tidal harbour and entrance to the docks at West Hartlepool. The bay and entrances to the harbours are well sheltered by the Hartlepool peninsula, and the tranquil area is further enlarged by the important pier works that have been in progress many years and are still incomplete. These operations and the work of deepening the entrances to the harbours are being carried out by the Hartlepool Port and Harbour Commission, a body composed of thirteen members, of whom five are elected by the North Eastern Railway Co. as proprietors of the docks, one by the Board of Trade, one by the Corporation of Hartlepool, one by the West Hartlepool Corporation, three by the shipowners of the port, and two by the importers and exporters. The breakwater was originally designed by the late Mr. James Walker in conjunction with the late Mr. Stephen Robinson, and has been extended under the successive superintendence of Messrs. Dyke, Howkins, and Belk. The Commissioners have also built, and maintain at their own cost, the entrance lights to Hartlepool, the principal of which was the first lighthouse illuminated by gas on the coast.

Dredging.—The dredging operations in connection with the harbour entrance have been most successful. Since they were commenced they have increased the depth of water from 2½ feet to about 14 feet at low water of ordinary spring tides; and during this period there have been raised and deposited at sea at a distance of three miles about five million tons of excavation, at an average cost of less than threepence per ton, including repairs, maintenance, and towing to sea.

Advantages of Port.—The more important points to be observed in noticing the port and industries of the Hartlepools are:—the advantageous geographical position of the port in relation to all the northern ports of Europe; its proximity to the great Durham coalfield, one of the most important in the kingdom; its exceptional physical features, rendering it a safe harbour of refuge and a favourite trading port; its large dock and railway accommodation; its immense timber imports, with the accompanying wood-yards and large saw-mills; its grain imports; its large coal exports; its shipbuilding and marine engineering industries; its iron and steel works; its cement manufactures, wire-rope works, paper-pulp works, fisheries, and egg-curing industries.

Docks.—The railways form part of the North Eastern system; and the whole of the docks and timber ponds, &c., are in the possession of the same company. The largest dock is the Victoria Dock at Hartlepool, which with the adjoining Hartlepool harbour was made over fifty years ago, when as yet there was no West Hartlepool at all. Since that time the whole of the modern town, with its docks and other industrial facilities, has sprung into existence, and still continues to develop at a rapid rate. The docks, basins and harbours now cover an area of 200 acres; and at the deep-water entrance there is a depth of 26 feet of water over the sills at high water of spring tides, with a width of 60 feet. The timber ponds occupy 60 acres, and there are 150 acres occupied in the storage of timber about the docks. The port employs ten steam tug-boats in dealing with the shipping, and has facilities by means of lock basins and hydraulic sluices for passing ships in and out at any state of the tide. The large warehouses of the North Eastern Railway cover 4½ acres, and are capable of storing 160,000 quarters of grain. The port is well supplied with hydraulic machinery, cranes, and sheer legs, the two heaviest of which are capable of lifting 80 tons each. There are also four dry docks, the largest of which is over 560 feet in length.

Imports and Exports.—Some idea of the extent of the shipping facilities at this port may be gathered from the following figures relating to the principal imports and exports. Of wood there is imported annually about half a million tons; of grain 300,000 quarters; of eggs 12,000 tons; and of general goods about 80,000 tons. There is exported annually a million and a half tons of coal, and nearly 100,000 tons of general goods. Lines of steamers run to Hamburg, Gothenburg, Belfast, and London. Plans are now out for the extension of the docks, and for additional coal-shipping appliances. A vessel carrying 9,000 tons dead weight, the largest that has ever entered the port, was lying in the middle of July at one of the quays, loading bridge and railway iron and other goods for India and China.

Shipbuilding and Marine Engineering.—By far the most important industries carried on at the Hartlepools are those of shipbuilding and marine engineering. The shipyards of Messrs. William Gray and Co., the Hartlepool Engine Works of Messrs. T. Richardson and Son, and the Central Marine Engine Works are to be visited by the members, and are described separately (pages 380–5).

The shipyard second in importance is that of Messrs. Furness, Withy and Co., situated at Middleton, and formerly carried on under the style of Messrs. Edward Withy and Co. It contains four large building berths, and keels can be laid up to 500 feet in length. The "well deck" type of cargo steamer has been made a speciality at this yard, and the majority have been built on the cellular bottom and web frame principle. The yard is replete with every appliance for carrying on work expeditiously and economically. The machinery is of the most modern description, and includes manhole-punching machines, flanging machines, hydraulic riveting machines, etc. Permanent rails or portable tramways are laid all over the yard to facilitate the transit of heavy weights. A feature in the shell plating here is the length of the plates, which in some recent examples have exceeded 50 feet in length. These works were the first to introduce steel wire-ropes for the purpose of checking vessels when launching. The large smiths', fitters', carpenters', joiners', and mast-makers' shops are fitted with machinery of the latest type. The scientific department of the drawing office has the newest instruments for making stability calculations, etc. One pleasing feature in the drawing office is the employment of young ladies for panel painting and other artistic work, in connection with the saloons and cabins of vessels.

The remaining shipyard is that of Messrs. Irvine and Co. at West Hartlepool, situated so as to launch into the West Harbour. This yard contains three building berths for vessels up to a large size; and there is also a dry dock in the yard, where a good repairing trade is done. Considerable improvements and extensions have recently been carried out at this yard, including new offices and stores, and the building of a new engineering department suitable for dealing with marine repairs and with the manufacture of steam winches, etc. A speciality is here made of salvage work, raising sunken vessels, etc.; and the extensive plant for this purpose has recently been increased.

Iron and Steel Works.—The principal iron and steel making works are the rolling mills called the West Hartlepool Steel and Iron Works, of which a separate description is given (page 385); and the blast furnaces called the Seaton Carew Iron Works. These furnaces were originally built in 1870 by the late Mr. Thomas Richardson, and were worked for a short time in a somewhat incomplete state. A serious depression in the iron trade necessitated the stoppage of the plant, which remained idle until 1883, when it was put into operation by the present owners. The furnaces were originally equipped with ordinary pipe-stoves, which were all cleared away and replaced by regenerative fire-brick stoves of the most modern design. The plant now consists of three blast-furnaces, 75 feet in height, each with a producing capacity of 900 tons per week. These are equipped with twelve regenerative fire-brick stoves, enabling an average temperature of about 1,300° Fahr. to be obtained before the introduction of the blast. There are four blowing engines: one by Messrs. T. Richardson and Sons, Hartlepool, with 45-inch steam cylinder and 100-inch blowing cylinder; two by Messrs. Kitson and Co., Leeds, with 45-inch and 100-inch cylinders; and one recently erected by the Tees Side Iron and Engine Works Co., with 48-inch and 100-inch cylinders. The boilers are at present being renewed, and when completed will consist of ten three-flued boilers 37½ feet long by 8½ feet diameter, working at 100 lbs. pressure. There are also the other usual adjuncts to a blast-furnace plant. The iron produced at present is wholly hematite of superior grade, a speciality being an iron extremely low in silicon, phosphorus, and sulphur.

Saw Mills.—The saw-mill industries of the Hartlepools, as might be supposed from the enormous timber imports, are of an extensive character. Among the more important establishments may be mentioned the saw mills of Messrs. Thomas Walker and Co., Robert Lander and Co., Harrison and Singleton, Christopher Brown, J. and T. T. Brown, and George Clark and Co. There are also several firms of timber merchants, such as Messrs. Wade and Co., May and Hassell, A. Livingstone and Co., George Horsley and Co., Pedersen and Co., and others, who do an extensive business without the use of mills.

The saw mills of Messrs. Thomas Walker and Co. are situated in Mainsforth Terrace, and are the oldest and largest in the port. They were commenced 42 years ago by the late Mr. Thomas Walker, and are now carried on by his sons. They cover an area of fifteen acres, and employ 230 hands. They contain a large amount of heavy machinery, amongst which may be named, besides the three steam engines, two steam cranes and one travelling crane, ten circular saws, three log frames, one deal frame, seven planing machines, two lathes, two general joiners, as well as sundry gulloting, drilling, morticing, tenoning, and moulding machines, and two special machines for manufacturing block flooring, which is a speciality at these works. Their principal speciality however is the woodwork of church fittings, for which they have a high reputation: some noted work, such as that in Stoneyhurst Chapel, has been done here. They convert a large amount of oak for wagon building and other railway work, and have extensive drying sheds filled with high-class timber, besides six wood-drying kilns.

The Newburn Saw Mills and Creosote Works of Messrs. R. Lander and Co. are situated in Mainsforth Terrace, West Hartlepool, and occupy an area of about nine acres. The plant and machinery is all of the best modern type, driven by steam-power. The owners of these mills import timber extensively from the Baltic, America, and Canada, and hold vast stocks of white and yellow pine, fir, redwood, and other standard varieties. They make a speciality of the manufacture of all kinds of builders' joinery, and railway station work, both for home and colonial requirements. Another speciality consists in railway sleepers and telegraph poles, which they are always in a position to supply in almost any quantity. The creosoting works of the same firm are in connection with the saw mills; and the establishment in all its departments gives employment to about 200 hands.

The Baltic Saw Mills, West Hartlepool, are the property of Messrs. Harrison and Singleton, who also have establishments at Bradford and Halifax. They were established in 1872 to facilitate the supply of timber to engineers and contractors in the West Riding and East Lancashire districts. These mills cover an area of thirteen acres, of which a large part is used for the storage and seasoning of timber for engineering purposes. The works have good railway accommodation and great facilities for quick despatch of goods. They are replete with every kind of machinery for converting timber of all sizes by means of steam power.

The Stranton Saw Mills, situated in West Hartlepool, were erected by their present owner, Mr. Christopher Brown, in 1878, and occupy five acres of ground. The works have grown with the town, and are now as extensive and complete of their kind as any in the North of England. The manufacture of every kind of woodwork requisite for the building trade is extensively carried on. The machinery is of the most modern description, comprising four planing and four moulding machines, one log frame, one deal frame, nine circular saws, one double-cut saw, band saws, tenoning and morticing machines, all of which are kept in constant operation. The works are well supplied with steam-power and railways. They are also among the largest importers in the kingdom of Swedish-made plaster-laths.

The saw mills of Messrs. J. and T. T. Brown are situated in Stockton Street, West Hartlepool, and cover an area of 1¾ acres. The principal building is a large three-storey brick building, fitted up with all kinds of machinery for the manufacture of builders' woodwork &c. There are also excellent sheds for the storage and drying of timber. The principal work here carried on is the preparation of doors, windows, staircases, shop and office fittings, and other woodwork required in the building trade.

Portland Cement.—The works for the manufacture of Portland cement at the Hartlepools are of a noted character. The largest are those of Messrs. Trechmann, situated at Hartlepool. These works were commenced about 1852 by the late Mr. Otto Trechmann, the father of the present proprietors. Ships of the olden build, which are still engaged in large numbers in carrying coal from Hartlepool to the Thames, bring back with them chalk as ballast. The chalk is utilized largely in the manufacture of Portland cement. A curious change has passed over the business of these works. In their earlier years the bulk of their manufacture was sent to the Continent. But as their trade declined abroad, it increased in vigour at home: so that whilst in 1870 their production was 200 tons per week, it is now 600 to 700 tons per week, almost the whole of which is consumed at home. The "Otto Trechmann" brand of Portland cement has won for itself a high reputation, and was exclusively used in the great Hury Reservoir and others built by the Middlesbrough and Stockton Water Board, in the works of the Manchester Corporation at Thirlmere, and in many similar undertakings.

The cement and brick works of Messrs. Casebourne and Co. are situated near West Hartlepool, and were established in 1863 by Mr. C. T. Casebourne. From 1866 to 1882 they were carried on under the style and ownership of Casebourne and Lucas, and since that time as a limited company. They are capable of turning out 400 tons of high-class cement per week, a large part of which goes into Yorkshire and Lancashire. Ten acres of ground have recently been purchased by the owners of these works, upon which has been put down a brick plant on the new Cummiss process, specially adapted for dealing with impure or stony clay. The present output is 60,000 bricks per week, of a quality equal to pressed bricks; the plant is the first of its kind put down in this country. The works also contain plant for making concrete flags, steps, kerbs, window-sills and heads, mantles, jambs, and all kinds of mouldings and copings.

Wire Ropes.—The manufacture of wire ropes is carried on at the works of the Hartlepool Ropery Co. at Hartlepool. These works contain the most modern appliances and machinery for the manufacture of wire ropes and cables of every description, mining ropes, aerial and road tramway-ropes, power-transmission ropes, agricultural ropes, and such as are used for hoists, cranes, general engineering and shipping purposes, together with the fittings necessary for their use. Ropes are here made to withstand stresses up to 1,000 tons. There are also wire mills for drawing and manufacturing all kinds of wire, machinery for making pickers for weaving machinery, staples, nails, rivets, &c.

Paper Pulp.—At West Hartlepool there are large works for the manufacture of paper pulp direct from wood, which are carried on by the West Hartlepool Paper Pulp Co.

Another interesting manufacture is that carried on by the British Metal Expansion Co., at West Hartlepool, of which a separate description is given (page 387).

Fish.—The fish trade at the Hartlepools is extensive, and is accommodated mainly by the large fish quay at the Hartlepool harbour, which consists of a covered quay or market 600 feet in length. One side of the quay adjoins the water for landing the fish from the boats and trawlers; and along the other runs the railway, so that the packed fish can be despatched to the interior of the country within the shortest possible space of time after its arrival. In connection with the fish quay there are large ice-stores and fish-curing establishments.

Sea Wall.—One of the most important engineering works carried out at the Hartlepools within recent years is that of the headland protection works on the north side of the Hartlepool peninsula. The magnesian limestone rock of which the cliff is composed had been gradually giving way to the force of the north-easterly gales, the encroachments of the sea being considerable within the memory of living inhabitants. For a length of three-quarters of a mile along the face of the cliff a heavy concrete wall is now erected, the top of which forms a fine sea promenade.

MESSRS. T. RICHARDSON AND SONS, HARTLEPOOL ENGINE WORKS, HARTLEPOOL.

This business was commenced upwards of sixty years ago by the father of the late Mr. Thomas Richardson, M.P. for the Hartlepools, and is now carried on by the sons of the latter. At first the works were employed in iron founding and railway plant; then in building stationary engines, principally for collieries; and afterwards in making locomotives. In 1851 the first marine engine was built, and during the following ten years the marine engineering branch increased rapidly and became in 1861 the chief manufacture. Since then, marine engines of various kinds have been constructed, and in 1883 the first triple-expansion engine on three cranks was built for the s.s. "Para," owned by Messrs. Steel, Young and Co., of West Hartlepool (Proceedings 1886, page 484). This engine was immediately followed by another of larger power for the Dutch Mail Co.; and from that date onward few engines of any other kind have been built. When in 1885 attention was being given to the conversion of old compound engines to the triple-expansion principle, the Union Company of Southampton decided on tripling their s.s. "Anglian" by adding a new high-pressure cylinder complete, making a three-crank engine. This alteration, carried out at the Hartlepool Engine Works, was attended with such success that six other engines of the same company's Cape mail steamers were subsequently altered in a similar manner. In addition to the foregoing, several vessels for the Castle and Orient Royal Mail Companies, as well as steamers of the mercantile class, have also been successfully tripled at these works. One of the largest was the royal mail steamer "Roslin Castle," having engines with cylinders 36 and 60 and 96 inches diameter by 60 inches stroke, and three double-ended boilers, each 14 ft. 4 ins. diameter by 17 ft. 9 ins. long. New engines and boilers have also been constructed at these works for the Peninsular and Oriental Steam Navigation Co., the China Shippers Co., Messrs. T. and J. Harrison, Liverpool, and other well-known companies. Several specialities closely connected with marine engineering are also manufactured in large quantities; these include evaporators, feed-water heaters, feed-water circulators, etc. In 1886 the first pumping engines of the three-crank triple-expansion kind were built for the East London Water Works (Proceedings 1892, page 432), their capacity being three million gallons per day lifted to a height of 600 feet.

Situated at G, Plate 58, the works consist of engine-building shops, iron and brass foundries, forge, boiler shops, and all the usual departments necessary for the construction of marine engines and boilers. The iron foundry has a capacity for making all the machinery and other metal castings required in the engine works, besides supplying a large outside trade, the total output being about 400 tons monthly when the works are in full swing. The buildings consist of three spans of 53 feet, 43 feet, and 33 feet, the total length being 350 feet. The forge has a capacity for making 200 tons of forgings monthly; and besides all the heavy forgings and shaftings for the engines made in the works, a large outside demand is also supplied. The boiler department consists of two shops, one having two spans of 55 feet and 43 feet and a length of 270 feet, the other having two spans of 45 feet each and a length of 142 feet.

The principal hydraulic machines are a large flanging press and a 140-ton riveter, both by Tweddell; a 60-ton riveter by Berry, Leeds, and a smaller riveter by Hugh Smith, Glasgow. A radial steam-hammer by R. G. Ross, Glasgow, is also employed for levelling plates; and a complete system of pipes is laid down for pneumatic caulking. The boiler finishing shop is served by a 75-ton self-contained overhead crane by Joseph Booth, Leeds. The machine shops occupy a large portion of the works, and contain machinery capable of dealing with the largest class of marine engines. The bay containing the heavier machines is 360 feet in length; and amongst these machines may be noticed a crank-shaft lathe by Shanks and Co., Johnstone, which is 30 feet between centres and capable of turning a diameter of 12 feet. On this lathe the crank-shaft of the "Roslin Castle" was finished in one piece, the diameter being 17 inches and the total weight 30 tons. There is also a vertical and horizontal planing machine by Shanks and Co., capable of planing a surface 19 feet high by 20 feet long; a large double-spindle horizontal drilling and tapping machine by G. and A. Harvey, Glasgow; and milling machines by various makers. The erecting shop, which is 175 feet long, consists of two spans of 60 feet and 30 feet, with a height of 50 feet from the floor to the crane rail; and is served by two 50-ton self-contained overhead cranes by Joseph Booth, Leeds, and 5-ton hydraulic jib-cranes by Hugh Smith, Glasgow. Adjoining the erecting shop is a bay 40 feet wide by 160 feet long, which is principally devoted to the manufacture of specialities. The copper shop is a building 90 feet by 60 feet, and is fitted with the newest plant, including hydraulic bending machine, pneumatic hammer, &c.

In addition to the works at Middleton there are repairing shops at the central 80-ton sheers, at the Union Dock 80-ton sheers, and at the Victoria Dock 60-ton sheers, the headquarters of the outside department being at the Union Dock.

CENTRAL MARINE ENGINE WORKS, WEST HARTLEPOOL.

These works, situated at H, Plate 58, were erected in 1883 and 1884 by Sir William Gray to meet the large demand of the shipyard belonging to his firm for marine engines. They were planned from the commencement on a large scale, and have since been extended so much as to cover an area of about ten acres. They stand on a site surrounded by favourable conditions, having along one side a quay fitted with 80-ton sheer legs, and along another side a dry dock 560 feet long, besides easy access by road and rail. There are five principal departments, namely engine shops, boiler shops, foundries, forge, and pattern shops; and a number of smaller, embracing brass foundry, copper shop, sheer-legs department, joiners' and painters' shops, tool fettlers', brass finishers', and stores. The forge also includes the smiths' department, the stern-frame and rudder-making plant, and the stamping machines. Thus every important process connected with marine engineering is here carried out, and the extent of each department is such as to meet the output of thirty to forty sets of marine engines and boilers per annum. About 1,500 hands find employment at these works.

The various departments were laid out with a view to economising as far as possible the labour of transit of material within the area of the works; and the placing of machines, &c., was done with the same object in view. In the engine and boiler shops the materials enter at one end, and progress through the various stages to the other, where they pass out to the sheer legs. The principal constructional features of these shops were described and illustrated in a paper read before the North-East Coast Institution of Engineers and Shipbuilders in 1887 (vol. 3, page 55), entitled "Construction of Marine Engine Works."

The first engine built at these works was on the triple-expansion principle, and was completed in October 1885. Since then the business has steadily increased, and all departments have now for several years been in full work. Some large cargo-steamers have been engined at these works, notably the s.s. "Rangatira" and the s.s. "Tekoa," vessels which carry about 50,000 frozen sheep carcasses from the antipodes to this country every voyage; the s.s. "Alberta" and s.s. "Arapahoe," sister ships carrying 7,500 tons dead weight; and engines are now in hand for a vessel of nearly 11,000 tons displacement, which is intended to bring home every voyage about 75,000 sheep carcasses.

All the engines manufactured at these works have the high-pressure cylinder placed between the other two, this arrangement being held to be conducive to economy of steam. A speciality in the manufacture of boilers consists in the welding and flanging of the cylindrical shell plates, and fitting thereto flat end plates, which are also welded at the corners of their seams. This method entirely obviates the joggling of one plate over another, and has other advantages which were fully described in a paper entitled "Some details in Marine Engineering," read before the Institution of Naval Architects in 1891 (vol. 32, page 212). The boiler shop contains heavy welding, hydraulic flanging, and hydraulic riveting machinery, for dealing with these special features of the boilers.

The engines and boilers manufactured at these works are noted for their high economy of fuel, as illustrated by the trials of the s.s. "Iona" carried out by Professor Kennedy for the Research Committee of this Institution (Proceedings 1891, page 200).

MESSRS. WILLIAM GRAY AND CO.'S SHIPYARDS, WEST HARTLEPOOL.

The North and South yards cover about ten acres at J, Plate 58, and are arranged for six building slips varying from 270 to 340 feet in length. The yards are fitted up with the most modern machinery for carrying on the work in an expeditious and economical manner, including special machines for flanging, riveting, and punching out large manholes. They are in direct connection with the North Eastern Railway. In the yards are shops for carrying out the whole of the requirements of iron and steel shipbuilding, such as joiners', smiths', fitters', riggers', painters', model makers', sail makers', mast makers', and tank, ventilator, and donkey-boiler building. The whole of the yards are fitted up with electric light. There are also two large graving docks opening into the wet docks, thus giving the advantage of being able to dock and undock at any time of the tide. With the facilities that are available in the way of machinery and travelling cranes, the yards are able to give great despatch to any ships that enter the docks for repairs.

The Central shipyard at I, Plate 58, covers about five acres, and is laid out for ships of 500 feet, the berths being specially piled to carry the heavy weight of such ships. Machines of the largest kind have been fitted up, including rolls 30 feet long, and a hydraulic bending machine for bending cold steel plates 24 feet long by 7-8ths inch thick. Railways are laid down in each berth for convenience in moving material. Both in this and in the North and South yards travelling cranes have been largely made use of. The Central yard is also in direct communication with the North Eastern Railway, and is fitted up with the electric light. There are also shops for carrying out the whole of the joiners', smiths', fitters', and painters' work. Large sheer-legs have been erected, so that immediately a ship has been launched she can go alongside the quay, and at once commence masting and taking on board her sundry fittings.

The three yards are together capable of turning out 60,000 tons of shipping per annum, and have recently built two vessels of 7,500 tons dead weight.

WEST HARTLEPOOL STEEL AND IRON WORKS.

These works, which occupy a site of twelve acres at K at the south end of the town, Plate 58, were originally laid out about thirty years ago; and after several vicissitudes—at one time being noted for their manufacture of iron rails—they passed in 1881 into the hands of the present proprietor, Mr. Matthew Gray, by whom they were rearranged for the manufacture of iron plates. In 1887 it was decided to add the manufacture of steel plates, for which purpose a large portion of the iron works was dismantled, and a complete modern steel plant laid down; and the first steel plate was made in August 1888.

The present plant consists of seven large Siemens steel furnaces in a line, with a casting pit in front of them, served by three 10-ton locomotive cranes, which deliver the ingots to a hydraulic charging crane serving three ingot furnaces: these are arranged in a circle, and each holds four ingots of 4 to 5 tons weight, which are withdrawn by the crane and delivered by it to the live rollers of the 36-inch cogging mill; the latter is fitted with tilting gear and all modern improvements. After being rolled in this mill down to the required size, the ingots are passed on by live rollers to a powerful set of bloom shears, which cut them into slabs of suitable sizes. The slabs are then lifted by a 4-ton locomotive crane, and transferred to bogies which convey them to the plate mills. Of these there are three, having a combined capacity of 2,000 tons of finished plates per week. No. 1 mill is a 26-inch pull-over mill, driven by a 36-inch horizontal engine; here the thinner plates and chequered plates are rolled. No. 2 mill is a 28-inch mill, driven by a 42-inch horizontal engine, and reversed by gearing. No. 3 mill is a 30-inch mill, driven by a Ramsbottom reversing engine having two 60-inch cylinders with 42 inches stroke, which also drives the cogging mill. There are also forty puddling furnaces with three 4-ton shingling hammers and a 22-inch forge train, to provide puddled bars for the manufacture of iron plates, which are rolled in the same mills as the steel plates. No. 3 mill and the cogging mill are in one line at right angles to the Siemens furnaces; and above them all runs a 25-ton overhead travelling crane for changing rolls or gearing, or lifting heavy ingots. This crane also passes over part of the casting pit, which is thus available for making large steel castings when required; but at present the only steel castings made here are steel rolls for use in the works. Steam is raised by twenty-six vertical boilers, and seven large 500 horse-power marine three-flued boilers, and several donkey boilers. The works are also fully equipped with fitting shops, test houses, laboratory, and hydraulic machinery for the economical and rapid handling of material, and are equal in every respect to any modern works.

The plates made here are so well and favourably known that these works were the only plate mills in the North of England which were not stopped during the Durham coal strike of last year; and even in the present slack times they are very busy. Among the contracts at present in course of execution are five for the British Admiralty, besides others for most of the leading shipbuilders and engineers in the kingdom; and plates are exported from here to all parts of the world.

BRITISH METAL EXPANSION WORKS, WEST HARTLEPOOL.

These works were laid out at L, Plate 58, adjoining the West Hartlepool Steel and Iron Works, for the purpose of carrying on a process invented by Mr. J. F. Golding of Chicago. The object of this process is to manufacture rapidly from thin flat sheets of steel a network or trellis that resembles in general appearance wire netting, but is much stronger than the latter. Besides the ordinary uses to which wire netting is put, this expanded steel or steel trellis makes strong fencing and hurdles; but perhaps its most important use is as a substitute for wooden laths in all kinds of lath and plaster work, rendering it fire-proof and eminently strong. The machine used is a kind of multi-bladed shearing machine, which nicks the plate through, but leaves a small piece solid between each nick and the next. The thin sheets of steel are thus slit up just as sheets of paper are slit in making fly-catchers; and the steel sheets are then opened out in the form of netting (Proceedings 1891, page 382).

MEMOIRS.

Herbert Howard-Keeling was born at Tottenham on 9th October 1829. After being educated at a private school and at King's College, he was apprenticed in 1849 to Mr. James Samuel, who was then engaged in making the Great Eastern Railway; and he was for some time at the works at Stratford. In 1853 he went to Russia to test some suspension-bridge bars on behalf of his uncle, Mr. Thomas Howard, of the King and Queen Iron Works, Rotherhithe. On the expiration of his apprenticeship he went to assist him at those works, in which he became a partner in 1861. He there invented an efficient mode of consuming the smoke from the furnaces. His uncle having died in 1872, he closed the works in 1873 and retired from business. He then took an active part in all local matters at Eltham, where he resided, and where his death took place on 7th June 1893, in the sixty-fourth year of his age, from an accident caused by his horse stumbling and falling upon him. He became a Member of this Institution in 1882.

Robert Cooper Sinclair was born at Hartshill, near Atherstone, Warwickshire, on 25th August 1825. He was educated for an engineer in the works of Messrs. Thornewill and Warham, Burton-on-Trent; and also by his father, who for nearly fifty years was resident engineer of the Coventry Canal; and he remained with him at Atherstone as assistant until 1857, when he opened an office in Birmingham for general practice as a consulting engineer. At the same time he was engaged in developing the Tame Valley Colliery at Wilnecote, near Tamworth. On his father's death in 1863 he was appointed his successor as engineer of the Coventry Canal. This position he held till 1879, and in addition carried out much other work in connection with gas engineering at Leamington, Coventry, and Dudley. He then removed to London, and became largely employed in brewery engineering at Wolverhampton, Burton-on-Trent, and other places. In 1892 he was about to proceed to South Africa as a contractor's engineer, but was prevented by ill-health. His death took place in London on 5th October 1893, at the age of sixty-eight, after a painful illness of some months. He became a Member of this Institution in 1857.

George Tilfourd was born at Elie, Fifeshire, on 28th November 1817. It was intended he should follow a sea-faring career; but after commencing he was compelled to relinquish it, owing to defective sight. After serving his apprenticeship to the ironmongery trade, he transferred his services first to an ironfounder, and then to the works of Messrs. John Brown and Co., Furnival Street, Sheffield, where he remained for many years, during which the conical draw-spring and plunger buffer were invented and perfected, and the large trade in laminated springs began to develope, necessitating the building of the Atlas Works, Savile Street East. The later portion of his life was spent with the firm of Messrs. Samuel Osborn and Co., Clyde Steel Works, Sheffield, the pioneers in adopting Mushet's invention of self-hardening steel. About the same time steel castings also came into use, and his energies were devoted to furthering the employment of these improvements. His death took place at Sheffield on 26th December 1892, at the age of seventy-five. He became an Associate of this Institution in 1884.

George Reynolds Turner was born at sea on 17th March 1826. He served his apprenticeship from 1842 to 1847 at the Sheaf Works, Sheffield, and was afterwards employed by Messrs. Sandford and Owen, Phœnix Works, Rotherham, in making wrought-iron wheels for locomotives, carriages, and wagons. In 1862 he commenced business at the Vulcan Iron Works, Langley Mill, near Nottingham, as a partner in the firm of Messrs. Russell, Turner, and Pender, makers of locomotive, carriage, and wagon wheels, railway wagons, constructive ironwork, and castings. Subsequently the firm was converted into the Langley Mill Engineering, Wheel, and Wagon Co., of which he became managing director. In 1873 he withdrew and built for himself new works, known as the Vulcan Iron Works, Langley Mill, where he developed the manufacture of railway wagons and tramcars, and began to introduce light portable railways and light and heavy rolling stock, coal-screening machinery, coal-sorting belts, underground hauling machinery, and other engineering work. Recently he travelled in Spain and South Africa, for the purpose of ascertaining the particular nature of foreign requirements; and he furnished complete equipments of portable railways in many parts of the world. His death took place at Langley Mill on 4th April 1893, at the age of sixty-seven. He was a justice of the peace for the county of Derby, and became a Member of this Institution in 1886.

Institution of Mechanical Engineers.

PROCEEDINGS.

October 1893.

The Autumn Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 25th October 1893, at Half-past Seven o'clock p.m.; Dr. William Anderson, F.R.S., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following twenty-seven candidates were found to be duly elected:—

MEMBERS.

Angas, William Moore,	Darlington.
Berry, John Ferrier,	Johannesburg.
Betts, Samuel,	Eskilstuna, Sweden.
Campbell, Andrew Chisholm,	Liverpool.
Hudson, William,	Ahmedabad.
Jenkin, Charles Frewen,	Tydu, Mon.
Langford, William,	Great Bridge.
Rounthwaite, Henry Morrison,	London.
Shroff, Adurjee Burjorjee,	Bombay.
Tasker, Frederick,	Sheffield.
Williams, Arthur Edward,	Dagenham Dock, Essex.
Wormald, Henry,	Featherstone, Yorks.

ASSOCIATE MEMBERS.

Bishop, Henry,	Lincoln.
Edmondson, Alfred Richard,	Manchester.
Stockton, Joseph Sadler,	Birmingham.
Thomson, James Watson,	Aberdeen.
Tomlinson, William Augustus,	Johannesburg.
Walker, Charles Christopher,	Sheffield.
Watson, George,	Kilmarnock.
Wilkins, George Cornelius,	Newcastle-on-Tyne.

GRADUATES.

Bealey, Harold Edward,	Middlesbrough.
Bedbrook, James Albert Harvey,	London.
Burtt, George Frank,	Brighton.
Douglas, William Saunders,	Consett, Co. Durham.
Fox, Frederick Joseph,	London.
Heinrich, Herbert Rodolph,	London.
Wort, Walter Edward,	Teddington.

The President announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

William Anderson, D.C.L., F.R.S.,	Woolwich.

VICE-PRESIDENTS.

Alexander B. W. Kennedy, F.R.S.,	London.
E. Windsor Richards,	Low Moor.

MEMBERS OF COUNCIL.

Arthur Keen,	Birmingham.
William H. Maw,	London.
James Platt,	Gloucester.
T. Hurry Riches,	Cardiff.
William H. White, C.B., LL.D., F.R.S.,	London.

Of these the following offered themselves for re-election :—

VICE-PRESIDENT.

E. Windsor Richards,	Low Moor.

MEMBERS OF COUNCIL.

Arthur Keen,	Birmingham.
William H. Maw,	London.
James Platt,	Gloucester.
T. Hurry Riches,	Cardiff.
William H. White, C.B., LL.D., F.R.S.,	London.

The following nominations had also been made by the Council for the election at the Annual General Meeting :—

PRESIDENT.

Alexander B. W. Kennedy, F.R.S.,	London.

Election as Member.	VICE-PRESIDENT.	
1881.	Edward P. Martin,	Dowlais.

MEMBERS OF COUNCIL.

1872.	Benjamin A. Dobson,	Bolton.
1873.	Henry Davey,	London.
1885.	Thomas Mudd,	West Hartlepool.

The President reminded the Meeting that according to the Rules of the Institution any Member was now entitled to add to the list of candidates.

The following nomination was made by Mr. Joseph Adamson, Mr. Ashbury, Mr. Barningham, Mr. Howarth, Mr. Walter M. Musgrave, Mr. Shenton, and Mr. Wren :—

MEMBER OF COUNCIL.

1881.	James F. L. Crosland,	Manchester.

The President announced that the foregoing names would accordingly constitute the nomination list for the election of officers at the Annual General Meeting.

The President gave notice, on behalf of the Council, that at the ensuing Annual General Meeting they would propose the following italicised alteration in By-law 15:—"Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, *if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years.* All compositions shall be deemed to be capital moneys of the Institution."

Also the following italicised addition to By-law 29:—"All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; *or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.*"

The following Paper was then read and discussed:—

"On the Artificial Lighting of Workshops"; by Mr. Benjamin A. Dobson, of Bolton.

At a Quarter-past Nine o'clock the Meeting was adjourned to the following evening. The attendance was 81 Members and 54 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Thursday, 26th October 1893, at Half-past Seven o'clock p.m.; Dr. William Anderson, F.R.S., President, in the chair.

The following Paper was read and discussed:—

"On the Working of Steam Pumps on the Russian South Western Railways"; by Mr. Alexander Borodin, Engineer-Director.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers, for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at a Quarter-past Nine o'clock. The attendance was 59 Members and 27 Visitors.

ON THE ARTIFICIAL LIGHTING OF WORKSHOPS.

By Mr. BENJAMIN A. DOBSON, of Bolton.

In manufacturing districts the use of Artificial Light is of considerably greater importance for work of all descriptions than it can be elsewhere. Whether the work be fine or coarse, delicate or bold, a better light is needed than for work which does not come under the head of manufacture. In Lancashire the staple industries of engineering, machine-making, spinning, weaving, bleaching, and dyeing, are mainly established in certain centres; and with them is invariably associated in the surrounding district the great coal industry. Although Lancashire coal has a number of excellent qualities, yet it is one that makes the most smoke of any. A large portion of the manufacturing industries, great and small, date from a number of years back, when smoke-consuming and smoke-preventing apparatus had not yet been devised; and many of the factories are working at the present day under pretty much the same conditions as when they started. Hence the atmosphere in all manufacturing towns in Lancashire is heavily charged with unconsumed carbon, producing an excess of cloud and fog, which, while inducing an excess of rain, acts also as a screen against the rays of the sun, and thus does a double injury to the neighbouring agriculturist, the producer of the country's native wealth. A circle of thirty miles radius around Manchester is said to include a larger population than an equal circle around any other place in the world; and within this circle, about twelve miles north-west of Manchester, lies Bolton, the town with which the author is best acquainted, where all winds, except the west and north-west, bring the surcharged atmosphere from other manufacturing districts, producing at any season of the year, if the wind happens to be slight, a sky ranging from dull lead to dark brown. For four years in succession it has occurred at the writer's works, that on the 21st of June, the longest day, the gas in every room, amounting to nearly 7,500 jets, has had to be lighted by eleven o'clock in the morning, and has remained lighted until work ceased; and this has occurred also in other towns, and in weather that ought to have secured abundant sunshine. To such an extent does gloom prevail that in clear weather the effect of bright sunlight becomes even distressing to the eye-sight, simply from the rarity of the contrast.

Requirements for a well-lighted Workshop.—Firstly, the light, if artificial, should be sufficiently intense to give the power of clear and natural sight over any portion of the work. For enabling the work to be performed with ease, the light should evidently be arranged to produce as nearly as can be the effect of natural sunlight. The light of the sun is diffused by the atmosphere; and unless its entrance is limited in extent, such shadows as it may produce are only natural shadows, so natural that the eye has no difficulty in following detail in any visible part. In this respect therefore artificial light should as far as practicable imitate the best natural conditions.

Secondly, the light should be so diffused as to avoid casting shadows, or placing any one portion of the work in too great relief, as compared with the general tone of the whole. If the work were being done in front of a window which faced the sun, a certain portion of it would receive an undue amount of light, and give a false idea alike of size and distance, owing to the contrast of the overlighted and underlighted parts. This might be a natural light, but would nevertheless be improper.

Thirdly, the light should be of such a character as to have no tendency to injure the sight by a blinding glare. This remark applies either to a good gas-flame or to the electric glow-lamp, from both of which the light is fairly well diffused; the rays being all comparatively weak are easily diverted and thus distributed. But the effect of having either a bright gas-flame or the still brighter coil of glowing wire before the eyes is exceedingly fatiguing and destructive to the sight, and in combination with the dust of workshops makes it a wonder that ocular diseases are not more common than they are.

Fourthly, the light should be of such a character as to leave the atmosphere free from noxious emanations. Any kind of natural or electric light will fulfil this condition. The artificial light that most infringes it is gas, which varies much from town to town, and even in the same town from time to time; but it is generally so impure as to be deleterious to health and comfort in the products of its combustion, which is always more or less incomplete.

Fifthly, the light should not unduly raise the temperature of the room in which it is employed. If on a hot day a gas burner has to be lit for every person in a crowded workshop, as has to be done in certain manufactories, the combustion of so much gas affects the temperature greatly, and thereby produces lassitude among the workpeople, together with various ailments which are almost in proportion to the amount of gas consumed.

Sixthly, the light should be simple, and capable of easy control. The whole arrangement should be so contrived that nothing but the simplest knowledge and experience are required for turning the light on and off. This implies of course both a central control and also various points of sub-central control.

Seventhly, the cost should be kept within such limits as will render the light practicable at the present day for those who have to make their livelihood by their special trade in open competition with the rest of the world.

Electric Lighting by Inverted Arc-Lamps.—Some years ago, while engaged in visiting and examining certain mills on the Continent, the writer was much struck with a mode of lighting which he then saw for the first time. This consisted in the use of electric arc-lamps of from 1,600 to 2,000 candle-power, suspended in a white enamelled reflector at a certain distance below the whitewashed ceiling of the mill. The first he saw was of 2,000 candle-power, and thoroughly lighted a large room of about 40 feet square with light sufficient to see to pick up a pin off the floor. The walls of the room, as well as the ceiling, were whitewashed. The light had a sort of bluish tinge, and looked like bright moonlight, but with much greater illumination and entirely without shadows. This appeared so striking that he made a few experiments at once, and found that it was possible to see into the interior of the machines and even underneath them in a way that up to then would have seemed incredible; and further that it was not possible to make a shadow of any description, even when holding a hat only two inches above the floor: all that could be seen in the centre of the covered part was a comparatively slight deepening of the shade. In other departments of the factory he found the same plan equally effective, and the diffusion of light so complete as to be astonishing.

Incandescent Glow-Lamps.—At that time the author's firm were engaged in replacing gas by incandescent glow-lamps on the Edison-Swan system in a large machining room at their own works, which is 345 feet long by 76 feet broad and only 12 feet high, containing 239 machines tended by 200 workpeople in the area of 26,220 square feet. The exigencies of trade had required that annexes should be constructed almost all round the building, thus further diminishing the amount of natural light that could gain admission. Along the whole of the centre of the shop, for a breadth of some 50 feet, gas was burning day and night; and in the close muggy weather of autumn and the fog-laden days of hot summer, the atmosphere of the room became most oppressive, in spite of the best ventilation by Blackman propellers; even at six o'clock in the morning, on entering the room, the smell was most objectionable. It was noticeable too that an undue proportion of the men suffered from diarrhœa, which was in fact a standard complaint, and furnished the constant explanation for absence from work. Although sometimes this was simply an excuse, there can be no doubt that the exhalations caused by the imperfect combustion of a gas not absolutely pure will suffice to explain the possibility of a large number of men being affected thereby.

The incandescent glow-lamps, each with its own switch, and covered with a wire guard, were attached to the gas brackets, which for this purpose were left just as they had been. Within a week of the application of these lamps, the importance of the third requirement, with regard to glare, was amply proved; for nearly every workman had devised a shade of one kind or another, some of white or brown paper, some opaque, and some translucent. No better device than this has been found; it does not look neat, being simply a make-shift; but it answers the purpose, costs nothing, and is applied in a moment. The results of the alteration were curious: the atmosphere was improved, the heat considerably diminished, diarrhœa as a general complaint ceased, and was at first succeeded by bronchitis, which however was found to be of a temporary nature, and disappeared as soon as the workpeople in that room had become acclimatized.

Nevertheless with the result of this lighting the author was not satisfied. The shop was as dark and gloomy as with the previous gas-lights. The number of lamps broken by accident and by carelessness was so great as to become a serious consideration, their price being out of proportion to their actual cost, and no allowance being made in regard to royalty in replacing broken lamps which had already paid royalty. The writer then made two further journeys to the Continent, in order again to examine the plan of the inverted arc-lamp; and on the first occasion returned more favourably impressed than before. The second journey was therefore made with the view of going more thoroughly into the details, and of concluding arrangements for conducting a trial of the plan in his firm's establishment. On this occasion he had the opportunity of examining a large weaving shed at Ruysbroek, near Brussels, on a dark winter night. The dynamo was driven from the main engine of the mill, and was a fine piece of work. Corridors lighted by incandescent lamps led thence to the vast weaving shed, which had the usual roof containing glass panels almost upright facing north, with a plastered ceiling sloping southwards from the top of each glazed panel, and lighted from an inverted arc-lamp in each bay between the pillars. The impression upon entering the doorway was that the large room was brilliantly lighted by the mid-day sun: no glare, no flames to be seen, but a golden light pervading the whole of the vast enclosure; the colour of the hair, complexion, and costumes of the workwomen perfectly distinct; under the looms not the slightest trace of shadow. In fact the result attained was an absolutely perfect ideal light for textile work. The bluish tinge of the arc light itself, when lighting direct, is more apparent than real, because it does not prevent the most delicate shades of colour from being appreciated. If however it is considered disagreeable or undesirable, it can be altered, as it was in this particular weaving factory, by mixing a trace of yellow with the ordinary white-wash; the ceiling is then still white, but the apparently bluish tinge is eliminated.

The result of this visit was the application of four inverted arc-lamps in the large low machining room at the writer's works. Over 50 tons of castings are daily taken in and out of this room; and there must be at least 300 tons of castings of various sizes and descriptions, in progress of treatment, stacked and piled in different places on the floor; there is therefore all the more necessity for good lighting in order to avoid accidents. The darkest portion of the shop was chosen, and the four arc-lamps were placed in approximately the best positions for lighting a certain area. The ceiling not being plastered, it was considered advisable to nail up to the joists light scantlings, which were afterwards white-washed. These lights have now been running almost day and night for about two years, and with unqualified success. The four arc-lamps have replaced twenty-six glow-lamps; but whereas each glow-lamp lighted up its own work only and a few inches around, the whole of the area lighted by the four inverted arc-lamps is bathed in a gentle temperate light, absolutely equal in all parts. This was encouraging, as an arrangement of this description involves a heavy expenditure; and it was therefore considered advisable to have further experience before going more largely into it. Moreover this plan of lighting would not always be applicable. If the ceiling were very low it would scarcely be practicable, because the arc-lamp must hang a certain distance below the ceiling and still leave head room. Also there are places where the amount of light required is so small that it would be injudicious to go to the expense of applying these lamps, which are capable of so much more duty. It was determined however to make an experiment on a practical scale at the author's works, and with this object to apply inverted arc-lamps for the lighting of a three-storey building with large attic floor above, the latter being used as an iron and wood pattern-room.

Fire Insurance.—With the object of avoiding any difficulty in the future it would seem advisable, before proceeding with the further development of the plan of inverted arc-lighting, to consult the insurance companies in each individual instance. The old style of insurance, where heavy risks were taken by one or two companies only, has now been altered, so that in large works such as those here considered, where the amount of insurance may be near £300,000, the risks are divided among a large number of different companies, who in their turn sub-insure their risks in other companies not primarily engaged. There is a tacit understanding between the companies that one surveyor may act for the whole of them in any one particular case, thus judiciously securing uniformity of action. But it unfortunately happened that the four lamps in question, which had been tried for some months at the works of the writer's firm, were lent by them, along with a dynamo and driving power, for the purpose of ascertaining how a certain cotton mill, which had the disadvantage that one corner of the bottom room was darkened by buildings outside, could be lighted so as to replace the missing daylight. The four lamps were placed in position and tested. The result was far beyond expectation. It was found that the cleanliness of the work, which is an essential requirement in cotton spinning, could be supervised to a degree hitherto unattainable by artificial light. The owners of the mill were then anxious to adopt this kind of lamp immediately; but they met with an absolute refusal from the insurance companies to allow any open arc-lamp to work in a cotton mill. This led to the question of its further use in the ironworks of the writer's firm, and at first a blank refusal was received, without any reason being given; but correspondence of some months resulted in permission being at length granted to continue its employment under certain rigid conditions. These indeed were reasonable as regards the conducting area of the wires, the voltage, safety fuses, and other necessary precautions.

In order to see whether there could be any valid objection to its use in cotton mills, the author made a fairly complete series of experiments. The danger in cotton mills is supposed to be that the finest fibres or filaments are liable in the process of spinning to escape in a certain proportion, under the action of the draught caused by the moving parts; and being of much the same specific gravity as the air, they are easily carried by upward draught. When they reach any ironwork, either columns, beams, shafting, or gas pipes, they have a tendency, owing to the latent electricity always developed in textile fabrics, to attach themselves radially to the electric or magnetic centre; and as the carding-room air in a cotton mill is always more or less charged with these floating filaments, the insurance companies feared the result of combustion by contact with the open arc would be that the fire would be conducted to a dangerous quarter by the loose filaments adhering to wires &c. This fear is found to be absolutely groundless. Repeated and extended experiments have in every case failed to show any indication of danger from such a cause. The fallacy of the insurance companies' objection is rendered apparent by the fact that at the present time they allow open gas-jets in all cotton mills. If there were any danger in an open arc-lamp, there would surely be more in open gas-jets, which of course are more numerous than arc-lamps would be. Furthermore the arc-lamps have to be lowered every eight hours of work for the purpose of changing the carbons. The gas-jets are turned off when not required, and lighted again when wanted; this may occur two or three times a day. But every time the electric lamp is lowered it is thoroughly well cleaned, which is especially easy, as it consists simply in wiping the wire and the inside of an enamelled reflector. To prove that the arc-lamps cannot convey fire by contact with the cotton fibre, the author has let fall in the inverted reflector quantities of what is termed cotton-fly, being the lightest and most inflammable part of cotton fibre; and as soon as the level of the arc was reached and the top fibres were ignited, the fire spread rapidly round the cone of the reflector and burnt downwards towards the bottom. When keeping the eye level with the top of the reflector, it was impossible to see anything escape over this level except the black tinder resulting from the combustion of the fibre or fly. With the true cotton itself, smouldering particles might be seen to the extent of from four to six inches above this level; but it was proved that these smouldering embers had no heat beyond that necessary to give them their colour, for they were not even capable of exploding gunpowder.

For the purpose of further elucidating the question of fire risk, the author visited a mill in Belgium, not far from Ghent, where very coarse numbers were spun, the cotton being of short fibre; and the amount of evaporation, as it is termed, of fly from the lower filaments was particularly great, the cotton used being of the poorest quality. Directly over the carding engines was an arc-lamp of more than 1,200 candle-power; and during four hours spent in watching and noting the effect of the lamp upon the fly, on not one single occasion was the slightest spark visible outside the reflector. Sometimes when the fly was unusually thick in the air, owing to a carding engine being brushed out, a slight corruscation could be perceived near the centre of the reflector, like the twinkling of a star; but this would only occur once now and then. Undoubtedly a certain amount of fly was consumed, because when the lamp was lowered for examination a residue was found in the bottom of the cone, composed of the very lightest tinder of cotton, but utterly uninflammable under any circumstances. In this country the insurance companies declined to countenance any experiments, on the ground that mill-owners had been satisfied up to that time with the ordinary gas-light and with their insurance regulations, and therefore they could see no good reason for a revolution of ideas. Furthermore the definite allegation was made that on two occasions fires had been caused in cotton mills abroad which were lighted with arc-lamps. Feeling the importance of ascertaining what amount of truth there was in this statement, the author wrote to the proprietor manager, and others interested in each instance. In the first it transpired that not a cotton mill but a cotton store had been burnt, which was lighted not by arc-lamps but by glow-lamps only; and the theory to account for the conflagration was that of spontaneous combustion, which is by no means rare when cotton is stored in bulk. In the second instance the lighting was not by the open arc-lamp inside an inverted conical reflector, but by an ordinary arc-lamp surrounded with a glass globe. There was an aperture in the bottom of the lamp; and owing to some disarrangement of the clockwork regulating the carbons, a portion of an incandescent carbon had been split off, and falling through the aperture upon a mass of cotton beneath had set it on fire. When cotton in a loose condition does get on fire, it is much like a train of gunpowder; and this mill, which was kept in a condition far from clean, being covered with a thickness of fly steeped in oil over the floor, walls, and ceiling, became so suddenly a mass of flame that the workpeople had considerable difficulty in making their exit from the burning building.

Arc-Lamp.—The complete absence of danger from the arc-lamp used by the author will be more thoroughly appreciated from a description of its construction. It consists of two carbons of different diameters, the upper or negative carbon being solid, and the lower or positive carbon being annular and rather larger in diameter. Their areas are 0·200 and 0·486 square inch respectively: which proportion ensures their both consuming at the same speed, thereby avoiding the necessity of any complicated clockwork arrangement to differentiate the speed of the feed. In this lamp indeed there is no clockwork, but the carbons are drawn together by a pulley, string, and counter-weight, their distance apart being regulated in the usual way by a magnetic brake. The pulley, weight, and brake are all contained in a cylindrical box attached to the underside of the cone of the reflector; and the only interruption to the light above is that occasioned by the thin arms forming the clip which holds the upper carbon. The crater carbon is here the lower one, in order that the larger number of rays produced may be thrown upwards. The cone reflector is 25 inches wide at the top and 7 inches at the bottom, the angle of the cone being 88 degrees. The interior surface is ordinary white enamel upon the sheet-iron exterior. The external appearance of the lamp is shown in Plate 59, and also the position the lamp occupies in relation to the white-washed ceiling; and in Plate 60 a portion of the detail is shown separately. Each lamp is balanced by a counter-weight over pulleys, Plate 59; and the counter-weight hangs conveniently alongside either a wall or a pillar, so that it may not be in the way of traffic. Thus it is easy to lower the lamp for the purpose of renewing spent carbons, which has to be done about every eight hours, and requires not more than one minute per lamp.

Practical Results of Working.—The plan of inverted arc-lighting has now been in use in some portions of the writer's works for twelve and thirteen hours a day during the last twelve months, and sometimes almost night and day; and the results of its working he has every reason to believe may be considered successful. The building, as already mentioned, consists of three storeys, each room 123 feet by 55 feet; the bottom room of all is surrounded to such an extent by other buildings that it was necessary to keep the gas burning the whole of the day. In this room the work consists of turning, fluting, polishing, and repairing what are known as fluted bottom-rollers for spinning machines. These rollers, illustrated in Plate 61, require to be finished with mathematical accuracy, and the majority of them have to be channelled or fluted to the closeness of from sixteen to nineteen flutes per inch, the shape of the flutes being of the greatest importance. In the room above are manufactured top rollers to work on the fluted rollers, Plate 62; these also have to be mathematically correct, and their surface finished to a high degree of accuracy. In the third room are manufactured what are known as flyers, represented in Plate 63, having one hollow leg, through which the cotton must pass down in a slightly twisted condition. Owing to the affinity of cotton fibre for metal affected electrically, however little, it is evident that any roughness of the interior surface of the hollow leg must be prejudicial to the working; and it is therefore necessary that the smoothness of finish should be unquestionable. The attic or roof room is used for the storage of patterns, as previously mentioned. In the bottom room there are 51 machines, consisting of lathes and fluting machines and others, and employing 60 workmen. The second room contains 164 machines, employing 139 workmen; and in the third room there are 69 machines and 112 workmen. The accompanying views of two of the rooms, Plates 64 and 65, show the position of the lamps that has been found to be most serviceable as the result of experiments. These views give an idea of the area lighted by each lamp, and also of the manner in which the reflected rays from one lamp cross and blend with the rays of the adjoining lamps. The only glow-lamps used are those in the attic or pattern store, most of which are portable for the purpose of finding patterns on the various shelves; and also, strange though it may seem, two glow-lamps in the bottom room, for the examination and repair of slightly defective flutes. The latter lamps had to be applied because the reflected light from the arc-lamps gives no shadow; and in order to perceive the minute defects in the flute it is necessary to have a light that will give a prolonged shadow, for the purpose of exaggerating what is to be seen. The writer quite thought it would be possible to accomplish the same object by the use of a reflector; but the prejudices of the workpeople were too strong.

When first this mode of lighting the rooms was set going, and the gas turned off at the mains, there was much grumbling of the workmen, who protested it was impossible to perform their work by the new light. This difficulty however had been foreseen, and they were informed that as the light had been put in at a large expense for their comfort and health, they must at least give it a fair trial. Within six weeks of starting its regular working, something occurred which prevented the requisite steam power from being furnished to the dynamo; and the gas had therefore to be turned on again, exactly as it had been in the former time. The result was a deputation to the manager on the part of the workmen to know what they were to do, as they could not see how to perform their work by gaslight; and on one or two occasions since then, when the light has failed through one cause or another, the workpeople have declined to work with the gas, stating that they preferred to wait until the electric light was on again, and that they could pull up the time lost.

Dynamo and Lamps.—The dynamo is of Belgian construction, and known as the four-pole dynamo. It runs at 600 revolutions per minute, and gives a voltage of 115. It is driven by a counter-shaft from the main engine driving the machinery in the building, and with 60 arc-lamps and 66 incandescent lamps it absorbs 70 horse-power. The lights are steady and free from flicker ; if ever a lamp is seen to flicker, it may be certainly concluded that it has not been thoroughly cleaned, and that the carbon slides are sticking in the magnetic brake. Photographs are exhibited of each room at ten o'clock at night in the winter ; they were taken of course from the reflected light itself, and the exposure was in each case rather less than ten minutes. Upon examination it will be seen that the detail is wonderfully distinct, even at the distance of 120 feet ; this is particularly noticeable in the photograph of the bottom room. Attention must be called to the absence of shadows. It can be seen that there are no dark places on the floor, and that underneath the lathes and other machines, although directly below the reflected light, there is no such thing as a defined shadow.

Horwich Locomotive Works.—Four inverted arc-lamps were tried by Mr. John A. F. Aspinall in one of the Lancashire and Yorkshire Railway workshops at Horwich, where however, owing to the great height at which they had to be fixed, they were not successful. They have since been placed in the large drawing-offices, and the light for drawing purposes is as perfect a light as can be. Failing on account of the height of the workshop to arrive at a satisfactory result with the solely reflected light, Mr. Aspinall has succeeded in lighting the main machine-shop with ordinary open arc-lamps, each protruding through a white-washed disc formed of light boardings framed together. A curious combination is thereby produced of lighting by the reflected and the direct rays. It has not the whole of the advantages of the reflected light, because the eye has a tendency to glance upward towards the dazzling arcs, and shadows are projected. Nevertheless the writer is convinced that by this combination of reflection a gain has been achieved of at least 25 per cent. over the ordinary direct arc-lighting without reflection; and all concerned are satisfied with the result.

Cost.—The question of cost of electric lighting, which after all is of the greatest importance, is somewhat difficult; and the writer is hardly in a position at present to give data sufficient to be of much practical value. Having regard to the number of workpeople who could be served with the light, the cost is less than that of gas, and of course the light is stronger and more general: so that in respect of candle-power it would be considerably cheaper than gas. In the three-storey building at the author's works there were 502 gas-jets, each burning four cubic feet per hour. Gas costing 2*s*. 8*d*. per 1,000 cubic feet would therefore come to something like 5*s*. 4*d*. per hour for this consumption. In the 60 electric lamps the only consumption is that of the carbons, which are reckoned at one halfpenny per lamp per hour. This has subsequently been reduced considerably; but taking this basis the 60 lamps would together cost 2*s*. 6*d*. per hour for carbons. The 66 incandescent lamps which are included in the 70 horse-power absorbed by the dynamo would of course add to this cost, as they are only 1,000-hour lamps. The greatest cost after the original installation is depreciation and horse-power. Taking the whole into consideration, it is probable that the cost of electric lighting would be more than that of gas; but as the light is so much more satisfactory, it may prove an economy in most cases to adopt it. Thus in the present instance the total candle-power of the 500 gas-jets would be roughly 8,500; while the arc and incandescent lamps combined would have 73,000 candle-power, much of which however is of course useless except for the general effect of the light. [See page 431.]

Conclusion.—The light now described has proved in practice to fulfil the requirements enumerated at the beginning of this paper as the necessary qualifications of a good artificial light, and for any class of manufacture for which it is applicable. For bleach and dye works, where it is necessary to distinguish minute differences in shades of colour, it must be invaluable, permitting this delicate work to be carried on in the dull winter days, which is now difficult if not impossible. If the insurance companies can be persuaded that not only is there no danger from this light, but that it is perhaps safer than any other mode of lighting, there seems every possibility that the use of this arc-lamp will undergo a rapid development.

Discussion.

The President said one of the inverted arc-lamps described in the paper had been sent by the author for exhibition alight in an adjoining room; and by the kindness of Messrs. Siemens Brothers the temporary wiring and connections necessary for enabling it to be lit up had been fitted, in order that the members might have the opportunity of seeing it in action. A lamp taken to pieces was also shown, for examination of its construction; together with a collection of photographs of the shops lit by this means, and specimens of the flyers and fluted rollers manufactured in these shops, as represented in the illustrations accompanying the paper.

Mr. John A. F. Aspinall, Member of Council, considered the description given in the paper of the atmosphere of Bolton was by no means overdrawn. There was no doubt that it was a particularly smoky place, where it was most difficult to get daylight into buildings which consisted of several storeys, and in which the rooms were of considerable width. Fortunately for the locomotive works of the Lancashire and Yorkshire Railway at Horwich they were about six miles away from Bolton, so that they did get the sunlight sometimes, and had not to light up so early in the evening or to keep the light going so long during the day as had to be done in the author's works in Bolton. In Fig. 10, Plate 67, was shown a cross section of one of the bays of the fitting shop in the Horwich works, Plates 68 and 69.

The wooden reflector R fixed overhead was about 13 feet diameter, and about 23½ feet above the level of the rails. In that shop it was absolutely essential to get the reflector put in the position shown, as no other place could be found in which it would not have been in the way of the belting or of some of the machines or of the crane which travelled up and down the shop, and of which the top of the jib was indicated at J. The lamps were arranged in three rows, as shown at L in the plan, Fig. 9, Plate 66, and at the height shown in Fig. 10. The arc was formed about 3¼ feet below the surface of the reflector. The area of the floor lighted by the lamps shown in Fig. 9 was about 151 square yards per lamp. The positive or crater carbon was the lower of the two, as shown in Fig. 11, and the rays of light were thrown upwards towards the reflector. He thoroughly agreed with what had been said in the paper about the perfect lighting which resulted from this system of reflection. It was not new, he was aware ; "the thieving ancients had stolen most of our modern ideas." Nevertheless he considered the author was to be thanked for drawing attention to the fact that this plan was so much in use in Belgium ; and it was after Mr. Dobson had spoken to him about it, and after he had himself seen the lamps, like the one now shown alight and illustrated in Plate 59, that he had tried an experiment to see what could be done with it at Horwich. That form of lamp however did not suit his workshop there; and he therefore simply used the ordinary lamps of the Brockie-Pell pattern which he had previously in use for lighting in the ordinary way, putting now the positive carbon below and the negative carbon above; and when the system was extended, special lamps were made to suit the workshop requirements. The result of this inverted position was that the positive carbon with its crater became a reflector. The positive carbon gave out about 85 per cent. of the light, the negative about 10 per cent., and the arc itself only about 5 per cent. ; so that as a matter of fact nearly the whole of the light got thrown upwards, and the lamp was burning so high above the eyes of the workmen that it really did not interfere at all with their work, even if they did glance upwards. It was no doubt due to the fact of the positive carbon giving such a large proportion of the light that it was not

(Mr. John A. F. Aspinall.)

considered necessary in street-lighting with arc-lamps to have a reflector above the lamp, the positive carbon being there the upper of the two. If the inverted form of lamp used in the workshop were placed much lower down in an ordinary room, then undoubtedly it would become somewhat inconvenient, unless there were a bottom reflector underneath it, such as was shown in Plate 59. The bottom reflector was open to the objection in certain manufacturing places that it was naturally a great collector of dirt, and required a good deal of cleaning. It was worth noticing in connection with the inverted position of the carbons, that the minute particles of carbon which dropped off the negative or upper carbon fell into the crater of the positive, producing at the moment a little flicker of the light, which was rather disagreeable if there was only a single lamp giving the light; but it did not appear to have the slightest effect on the light, where there were a large number of lamps in the room.

The Honourable Charles A. Parsons believed that about fifteen years ago a somewhat similar lamp had been devised in Paris by Messrs. Sautter Lemonnier and Co.; but at that time the carbons were imperfect, the regulation of the lamp was not sufficiently accurate, and the result was not at all satisfactory. With the present improved carbons and automatic lamps the light was absolutely steady, and the effect of the illumination very good indeed. For workshops the light was admirable; it so closely resembled daylight that workmen could see the smallest work with perfect clearness, much more so than with gaslight or the ordinary incandescent lamp. It seemed possible that this system of illumination might be extended to further uses than those of the workshop, such as large halls, libraries, museums, and places of public resort, where it might be applied on a large scale and might well replace glow-lamps and other modes of lighting. This form of illumination he thought was much more economical than the ordinary incandescent lamp, in respect both of total cost per total candle-power usefully distributed over the area to be lighted, and also of first cost and of the amount of electrical energy required; and in his opinion it would no doubt become in the near future a largely recognized and generally useful and extended system of using the arc-lamp.

The President asked whether Mr. Parsons used this mode of lighting in his own works at Gateshead; and if so, what was the power of the lamps employed.

Mr. Parsons replied that his firm had a certain number of these inverted arc-lamps in use, and a certain number of ordinary arc-lamps as well; and they intended to adopt the inverted lamps generally throughout their works. The inverted arc-lamps were pre-eminently suited for low workshops, where arc-lamps of the ordinary kind could not be used. The inverted lamps could be placed about 15 feet apart, and the light was then practically uniform all over the floor. Some of the lamps were of ten ampères and some of fifteen. There was apparently a very small loss of light from the whitened surfaces of the reflectors; and the high initial light-giving efficiency of the arc rendered such loss of small moment. Some fourteen years ago, the late Sir William Siemens had tested the distance at which the direct rays of an arc light were visible, and then the distance at which a white screen illuminated by the same arc was equally visible; and he had been surprised to find that in many states of the atmosphere the screen was the most clearly seen of the two.

Mr. James Platt, Member of Council, had had an opportunity of seeing the lamps at Horwich, and had been much pleased with the effect, in the drawing office particularly, which was a room 16 to 18 feet high with a flat ceiling. The light was perfect for the draughtsmen; and in the large shops it was exceedingly good. He was so much pleased with it that it was about to be adopted in his own works.

Mr. Henry J. Rogers suggested that the difficulty with the insurance companies might be got over by having a clear glass dome over the conical reflector described in the paper.

Mr. E. C. de Segundo thought any system of lighting by reflection must necessarily be more expensive than lighting by direct rays. The cost, as rightly remarked by the author (page 409), was after all the chief thing to be dealt with ; but a calculation of the relative cost naturally involved a determination of the relative illuminating efficiency, and the latter might be much a matter of opinion. According to the figures given in the paper, it appeared that, with gas costing 2*s.* 8*d.* per 1,000 cubic feet, the cost of gas consumed by the 502 gas-jets at the author's works had been about 5*s.* 4*d.* an hour. The cost of carbons for the 60 arc-lamps was reckoned to be 2*s.* 6*d.* per hour. Judging from the statement that 70 horse-power was absorbed in supplying 66 incandescent and 60 arc-lamps, he calculated that the former must be 60-watt lamps and the latter 15-ampère lamps. If then to the halfcrown per hour for the carbons there was added the cost of the horse-power, it appeared to him that the total cost would amount to considerably more than it ought for the amount of light produced. The candle-power of the 500 gas-jets was said to be roughly 8,500 ; and it was also stated that each gas-jet burnt four cubic feet per hour. It must be a remarkably good gas-jet he thought which would give seventeen candle-power for four cubic feet of gas per hour. The arc and incandescent lamps combined were said to have 73,000 candle-power; but he feared a good deal that was said about candle-power of arc-lamps was without sufficient warrant. One thousand candle-power was often spoken of as being obtained from an arc-lamp consuming from 500 to 750 watts. In testing arc-lamps which were said to yield 1,000 candle-power, he had found in one instance only 300 candle-power recorded by the photometer at an angle of about 30° with the horizontal. On this system of reflected light it seemed hardly right to speak of the candle-power of the arc-lamp, because the overhead reflector was really absorbing a great part of the light. The amount of light reflected from a white-washed ceiling would of course become less and less as the white-wash lost its original whiteness; and even at its best a white-washed ceiling could hardly be very efficient as a reflector. If it were necessary, as described in the paper, to guard against the extension of any combustion of the cotton fly, why should not the reflector surrounding the arc-lamp be made of some translucent material, so as to allow some of the rays to come directly down through it? Such a light he thought would not necessarily throw any distinct shadows; and it seemed to him that the opaque conical reflector surrounding the arc light described in the paper would be more conducive to a general shadow than an opalescent shade. It would seem strange if the uniform lighting of a workshop could not be effected except with so large an amount of light. It would be difficult at first sight to form an opinion as to how much of the light was lost by being used in that way; but he thought it must be considerable, because in page 401 of the paper it was stated that four inverted arc-lamps had replaced twenty-six glow-lamps. Those arc-lamps would apparently be 750-watt lamps, that is roughly lamps consuming 15 ampères at 50 volts. Therefore the four arc-lamps must together consume about 3,000 watts. Assuming the twenty-six glow-lamps to have been 60-watt lamps, the electrical energy required for them would have been about 1,600 watts. Therefore a considerably greater lighting effect should be expected from 3,000 watts when used in the arc-lamps than from 1,600 watts used in the incandescent lamps. In arc-lamps one candle-power at least ought to be got for 1·7 watt; and therefore arc-lamps consuming 3,000 watts of energy should amount to about 1,800 candle-power, as against 26 × 16 = 416 candle-power for the incandescent lamps. In page 401 it was said that, whereas each glow-lamp lighted up its own work only and a few inches around, the whole of the area lighted by the four inverted arc-lamps was bathed in a gentle temperate light, absolutely equal in all parts. From such an expression as a gentle temperate light it was evident that the diffusion of the light must be very complete, and the illuminating effect pleasant; but it must be remembered that the intensity of light had been increased 1,800 ÷ 416, or about $4\frac{1}{2}$ times, and the electrical energy consumed had been increased about twofold. If some reliable photometric measurement could be obtained under both conditions, it might be possible to judge of the relative efficiency; but he doubted whether the energy of 3,000 watts which was being used in

(Mr. E. C. de Segundo.)

the arc-lamps was being used to the best advantage. With some other kind of reflector, of opalescent or translucent material, instead of enamelled iron, the same effect he considered ought to be produced with much less expenditure of energy.

The attitude of fire insurance companies to electric lighting was at present often anomalous. It seemed absurd to allow naked gas-lights in a cotton mill, and to refuse to allow arc-lamps.

In page 403 it was stated that the arc-lamps had to be lowered every eight hours of work for the purpose of changing the carbons. But at the present time arc-lamps were made which were working satisfactorily for at least 32 hours; and one was now being made to work 64 hours, while it was hoped eventually to increase the duration to 128 hours. It was needless to say how cordially he agreed that electric light was superior to gas for workshops; but it seemed a pity that the particulars of cost which were so essential were not yet forthcoming with more accuracy. If a separate plant were erected for the generation of the electrical energy required for 66 incandescent lamps and 60 arc-lamps, the electric lighting by these lamps could undoubtedly be produced at a lower cost than the equivalent lighting by gas, taking all circumstances into account; and therefore he could not understand why the author thought it probable (page 409) that the cost of electric lighting would be more than that of gas; for he had his own mill engine from which the driving power was taken, so that this power was obtained in the cheapest possible way next to water power. Hence the cost of the electrical energy in this instance should be considerably less than the author appeared to think. If some better plan could be devised, whereby the light, which was now absorbed unnecessarily and he thought wastefully, could be diffused, it was probable that half-unit arcs might be employed, requiring each only 500 watts instead of 750. In 60 arc-lamps that would make a difference of something like 20 horse-power. In the incandescent lamps he thought not much improvement could be made; but now that the first cost of these lamps was becoming reasonable, it occurred to him to suggest that it might be found economical to use a larger number of incandescent lamps working at a much higher efficiency, namely at an efficiency approaching that of the arc-lamp, that is to say at about two watts per candle-power; and then to replace each lamp when it became too dim. An incandescent lamp he thought might be used at an efficiency of two watts per candle-power, and would then last about one-third of its present reputed life of 1,000 hours; that is, it might be calculated to last about 300 hours. If the first cost of incandescent lamps were to come down to one shilling each—and he did not see why it should not, judging from their intrinsic value and from the numerous improvements made for facilitating their manufacture—he thought it probable that for lighting workshops it might be found economical to use incandescent lamps of this higher illuminating power, properly shaded in the manner in which the author mentioned (page 400) that he had found the workmen had shaded their glow-lamps. Shades of various degrees of opalescence could be obtained for incandescent lamps; and instead of having naked arc-lamps shielded by a reflector which necessarily absorbed so much light, it might be more economical to apply incandescent lamps direct, and change them when their brightness waned.

Mr. Dobson asked if Mr. Segundo had seen the arc-lamp which was shown in action in the adjoining room.

Mr. Segundo replied he had not done so yet.

Mr. Henry Human, being surveyor to an insurance company, would refer to that portion of the paper which treated of the fire risk. In the case of engineering works, or works where nothing of an inflammable nature was dealt with, there could be no objection to the arc-light; but in cotton mills a different condition of things had to be met. In point of inflammability, cotton was well known to be second only to gunpowder; and it was necessary therefore to be most careful what light was introduced into such places. The impression was conveyed in the paper (page 403) that the chief danger of arc-lighting in cotton mills was the burning of naked arc-lights in the presence of cotton fly. This theory was at once refuted by the fact that naked gas-lights had been used for years past in cotton mills

(Mr. Henry Human.)

without any apparent danger so far as the fly was concerned. But he would point out that, if gas-lights were liable to drop particles of incandescent matter, then assuredly they never would have been used in cotton mills, except under extraordinary precautions; and it was the liability of particles of incandescent carbon escaping from the arc-lamp that rendered its presence in cotton mills so exceedingly dangerous. Though he was not acquainted personally with either of the two cases referred to in the paper (page 405), in which fire had been attributed to arc-lighting, it was clear from what was there stated that the first did not apply, for the reason that there was no arc-lamp in that building. The second case however did apply, and was clear evidence of the danger attending the use of ordinary arc-lamps in cotton mills. Some further explanation seemed desirable as to how it was that there came to be an aperture in the bottom of the lamp in that instance: whether it was due to defective construction of the lamp itself, or to some negligence on the part of the trimmer. There was yet another case, which touched more particularly upon this form of inverted arc-lighting. It was a cotton mill at Luneville in France, which was destroyed by fire in December 1892, as the result of an accident with a Pilsen inverted arc-lamp, similar in external appearance to an ordinary arc-lamp, but with the poles reversed, the crater carbon being below. Attached to the lamp was an inverted conical reflector suspended by chains, and made detachable to admit of trimming. In order to trim, it was necessary to detach only one chain, thus tilting the cone and thereby giving sufficient space to get at the carbons. On the occasion of the accident, the lamp had been re-trimmed at one o'clock in the morning; and it was assumed either that the trimmer had neglected to re-fasten the attachment properly, or else that a part of the lamp had given way. At all events, half an hour afterwards one of the suspending chains fell, tilting the cone violently on one side, and causing an incandescent particle of the carbon to fall upon the cotton in a spinning mule beneath. The place was immediately in flames, the fire spreading with fearful rapidity, and resulting in the destruction of the mill. The falling of a suspended lamp was by no means an uncommon occurrence, particularly of a heavy lamp with a correspondingly heavy counter-weight upon the suspending gear. Moreover, however well a lamp might be designed and constructed, it was still largely dependent upon what was after all a more or less unknown quantity, namely the human factor; for it was the trimmer rather than the lamp that was most to be feared. Should one of these lamps fall, in either the spinning or the carding room of a cotton mill, the result would probably be as disastrous as the tilting of the cone in the Luneville mill. The fire offices had now been twice bitten; and on the principle of "once bitten, twice shy," they were more than twice shy of admitting arc-lamps into cotton mills.

Mr. James M. Small drew attention to a point not noticed in the paper, namely the necessity in large factories of providing for the prevention of panic in the case of a breakdown of the dynamo. His partner and himself having lately been consulted as to lighting a large jute factory in Scotland had there arranged for what was called a "police" circuit. The regular lighting of the mill itself was carried out by about 700 incandescent lamps, which were run directly from the dynamo; but in addition there was this independent police circuit, comprising 70 lamps, which could be supplied either by accumulator batteries, or, as was actually done in this instance, from the town circuit, that is, from the central station in the town itself. During working hours the mill was lit by the 700 lamps driven from the small dynamo; but an arrangement was provided whereby, if the dynamo were to break down, the police circuit would be instantaneously switched in. This prevented any chance of panic, such as might be likely to occur in a textile manufactory where there were a large number of women engaged. Not only was it useful in the case of a breakdown, but it could also be employed in the early morning for getting things ready and allowing the workpeople to come in; and again in the evening for allowing them to go out, instead of having to keep the dynamo running, which would probably mean keeping the mill engine running. For the purpose of switching the police circuit in, the simple arrangement shown in Figs. 14 to 17, Plate 70, was employed. It consisted of a

(Mr. James M. Small.)

cast-iron magnet M with a coil L round it. The armature A was pivoted on a centre C; and the position shown in Figs. 14 and 15 was that during the daytime when the dynamo was not running, the armature being then held up pretty near to the face of the magnet M by a small catch H. The coil of the magnet was connected with the mill dynamo through the terminals TT. As soon as the lighting of the mill was started, the armature was attracted by the magnet and held up by it so long as the mill dynamo was running; and the little catch H dropped down into the vertical position shown by the dotted lines in Fig. 15. If the mill dynamo happened to break down, the result was that the armature, being no longer supported by the magnet, instantly fell into the position shown in Fig. 16, and the knife K entered into the switch S, Fig. 17, which was connected with the police circuit PP. When the dynamo was got to work again, the armature was turned up again to the magnet by hand, disconnecting the police circuit, and tripping up as it rose the catch H. This simple arrangement had now been working for a short time, and he had received a report a few days ago which stated that it acted admirably. Some such plan he thought might well be introduced in all cases of mill lighting.

Mr. William H. White, C.B., Member of Council, had visited the works of Messrs. Sautter Lemonnier and Co. in Paris on the occasion of the Exhibition there in 1878, and had seen them lighted upon a general principle resembling that described in the present paper. The building was one which it would be difficult to light satisfactorily; there were a number of pillars supporting an upper floor, and there was a good deal of machinery to be kept working. The result however was perfect, so far as diffusion of light and absence of shadow were concerned; and it had often been a surprise to him that the plan had not been more largely adopted in machine shops in this country; he was therefore all the more glad to learn that Mr. Dobson had now worked it out so successfully as he evidently had done. Criticism hs to cost, or as to the best electrical arrangements, was in his own opinion subordinate to the main fact that this mode of lighting, applied in the manner described in the paper, was found to be eminently satisfactory for the purpose for which it was intended. As bearing upon this point, he well remembered that some years ago, after a considerable amount of experience in the north of England, and with the assistance of Mr. Parsons, he had arranged for portable electric lighting appliances to be used during the construction of warships, in the interior of which there was so large an amount of work to be done in confined spaces. But on subsequently coming to consider the application of the same plan in the Government dockyards, he was met with a statement that the cost of the candles and gas which had been burnt during the construction of a battle-ship was very moderate when compared with the outlay necessary to procure the proposed plant for electric lighting, and its subsequent cost for maintenance and depreciation. He had not attempted however to argue the matter then further than to say that he knew as a solid fact that the larger expense in electric lighting was more than recouped by the results which were obtained in the work done; and no doubt the author would say the same with regard to his mode of lighting his own works.

Mr. A. P. Trotter thought one reason, which might account for the fact that so little attention had been paid to this mode of lighting, was that people did not believe white-wash to be as good a reflector as it really was. If a sheet of white paper were held behind a candle, a reflected beam could not be cast by it on the wall, as could be done by a looking-glass; and it was immediately inferred that white-wash was not to be compared with a looking-glass for reflecting light. As a matter of fact, this was quite a mistake. The looking-glass would reflect in one direction only, whereas the white paper reflected in all directions. The reflecting power of white paper could not easily be measured without going into rather complicated calculations, because the light varied with the cosine of the angle of incidence. Such measurements had been made by himself, and had been repeated with much greater accuracy by Dr. W. E. Sumpner, who had made experiments on the reflecting powers of many different substances, and had found that about 82 per cent. of the incident light was reflected from white blotting paper. Such a

(Mr. A. P. Trotter.)

percentage was in fact higher than could be got through an opal or ground-glass globe, which often absorbed more than 20 per cent. As a matter of fact a dirty glass, of an ordinary glass globe or lantern, would frequently absorb 15 per cent.; and then there were shadows, in which perhaps more than 95 per cent. of the light was lost. With the mode of lighting described in the paper there were no shadows; and if the white-wash was clean there was a reflection of about 80 per cent. of the light. Photometrically this would compare favourably with any other mode of lighting; and it seemed, in cases where it could be used, to be the best plan of applying arc-lamps. The only question—one which might have to be considered in railway stations, for example—was the cost of white-washing.

The value of such a reflector depended entirely upon the solid angle which it subtended at the arc of light. The reflector shown in Fig. 10, Plate 67, appeared to subtend an angle of something like 120° or more; and it was essential that the reflector should be large, or else nearer to the lamp, so as to subtend not less than that angle. The amount of light lost by the conical hood would be but little; for it would be seen that with the inverted arc, as shown in Fig. 11, hardly any direct light from the carbons went away below the horizon. It was therefore no use putting a white-washed reflector above an ordinary arc-lamp in which the positive carbon was above the negative, because in that case hardly any light went above the horizon. In the same way an opalescent hood beneath the inverted arc-lamp would let scarcely any light worth speaking of pass down through it.

Professor Alexander B. W. Kennedy, Vice-President, had been much interested in reading the paper when it was originally printed for the previous meeting, and had gladly taken advantage of Mr. Dobson's experience as therein set forth, and also of what he had heard from Mr. Aspinall, to recommend the use of this plan of lighting in one or two places where he thought it would be found to be exactly what was wanted. He had been so much pleased with the way in which it worked out, that he had been thinking with Mr.

Trotter that it seemed a wonder it was not used a great deal more, seeing that it was available for so many purposes. For instance he had lately had to consider the lighting of rooms in the art school of a town in the north, where for years past there had been assembled every evening during the winter some seventy men and boys working at drawing, with sixty-eight gas-burners in one room—a gas-burner for each drawing-board. The atmosphere of the room when so occupied must have been appalling; and the dirt in the room was certainly terrible, as might be expected after the use for some years of sixty-eight gas-burners not very carefully regulated. The whole room could be lit perfectly, after it was white-washed, by a couple of inverted arc-lamps; and the advantage of such a plan he believed would be great in respect of health. He had also met with several other cases where the plan might advantageously be employed. What the author really seemed to want was to get light from as many points as possible; and he carried out that object by using for the source of light, not the small arc itself, but a huge reflector of slightly rough material, which practically gave off light from an enormous number of points, as had been explained by Mr. Trotter. Those who had not yet seen the reflected light which was on view ought not to leave the building without visiting the room in which it was exhibited. The absence of shadows underneath the hood was really remarkable, and could scarcely be believed without actually seeing it with their own eyes. The whole floor was lit up by the light coming, not from the place where the arc-lamp was, but from the entire surface of the ceiling; and the natural consequence was that the floor underneath the conical hood was lit up from portions of the ceiling that were beyond the angle of the cone.

On one point he thought the author had been slightly misled. It seemed to have been forgotten in the paper that even in these modern times arc-lamp makers had adopted one of the most antiquated and objectionable expressions in the phraseology of mechanical engineering. They had adopted a "nominal" candle-power, which bore inversely somewhat the same ratio to real (mean spherical) candle-power that nominal horse-power bore to real horse-power: that is to say, instead of getting really double or treble or quadruple

(Professor Alex. B. W. Kennedy.)

the candle-power that they were supposed to get, they really got only half or a third or even less of the nominal light. Where therefore lights of 1,600 to 2,000 candle-power were mentioned in the paper, it was important to bear in mind that these were merely nominal quantities, and instead of being multiplied must be divided by two or three or four in order to get the actual mean candle-power. The question dealt with in the paper however was of course not really candle-power at all; it was the question of a thoroughly good and satisfactory method of illumination, to be used under singularly difficult circumstances; and the probability was that the applications of this method of illumination would be much more numerous in the future than had hitherto been thought of.

The President said that, without professing to know much about electricity, he certainly thought the method of lighting described in the paper was not only good, but must also be economical. At the Royal Arsenal, in one of the factories in which small work was done, and which was lit up by arc-lamps and glow-lamps, the roof was a saw-tooth roof, like that of a weaving shed (page 400); and it was difficult on that account to get direct reflection from the ceiling. The point which always struck him when visiting that part of the Arsenal in the evening was, what an enormous stream of light must be thrown out upon the sky; for with the direct light of the arc-lamps a large proportion went out through the glass roof, and was wasted outside; whereas, if reflectors were applied, the bulk of that light would be thrown back into the building and become usefully employed. With the direct-acting arc-lamps, even when shielded by ground-glass globes, it was impossible to do without glow-lamps at the machines engaged upon small work, because of the strong shadows thrown from the arc-lamps. On an inspection of the lamp exhibited in the adjoining room, he was much astonished to find that there was no shadow at all; he could read from a book with the back of the book to the light and his own face towards the light, quite as well as if the face of the book was turned towards the source of light. Such a result certainly surprised him greatly, and induced him to think that for workshop purposes this method of lighting, in which there was no shadow whatever, would be highly advantageous, however costly it might be, because the small glow-lamps, which otherwise had to be employed for supplementing the general lighting by arc-lamps, were expensive in every way, and were not easily manœuvred about when small work had to be done.

Mr. Dobson said the paper was not intended, and made no pretension, to be a scientific treatise. His experience had been obtained in a rough and ready way, when making experiments for his own firm; and he was himself so satisfied with the results of those experiments, that he thought it perhaps his duty, and a pleasant duty it was, to give the benefit of his experience, and so possibly to shorten the labours of others in the same direction. The most difficult point connected with the subject he thought was the question of reflection. It had been explained clearly by Mr. Trotter (page 421) why a white-washed ceiling was such an admirable reflector; it was both a reflector and a refractor, and in fact it had every action upon the light that it ought to have. If therefore employers would only spend a small sum a year in white-washing the ceilings of their workshops, the expense would be saved in gas or electricity over and over again. Experiments with opalescent and ground-glass shades had been made on many occasions, and had invariably failed. The thinnest clearest glass over one of the conical reflectors was sufficient to dim the light so greatly as to frustrate the whole plan. First of all, glass itself intercepted a great deal more light than he believed any scientific investigation had yet given it credit for. In the second place, when it had been on five minutes in the workshop it had already acquired a film of dust, which, added to the effect of the glass itself, was sufficient to reduce seriously the value of the light; and that reduction went on steadily, until it was necessary to take the lamp down and clean it, because it did not give its light. As pointed out by Mr. Aspinall (page 412), in a shop where there was dust of iron and steel constantly flying about in the atmosphere there must be a deposit of it in any place where it could fall; and it fell into the lamp, which in due course required cleaning.

(Mr. Dobson.)

In connection with the fact that the arc-lamp had to be lowered every eight hours for the purpose of renewing the carbons, it had been mentioned (page 416) that there were lamps which would last 16, 32, and 64 hours, and that one was contemplated which would last 128 hours. The longer duration was obtained by the use of parallel carbons, so that the arc could change from one set to the other, and regulate itself in that way. Having tried the plan, he had found the result to be that every time the arc changed from one set of carbons to the other there was a distinct flicker, whilst the object aimed at with these inverted arc-lamps was to make them as steady as possible. The lamp now exhibited alight in the room adjoining was not absolutely steady, the reason being that the carbon was not absolutely pure; but carbons were already much better than they ever were before. Whenever the carbons became perfect, the lamp would burn without the least flicker. The reason the lamp had to be lowered every eight hours, in addition to the fact that it was a lamp in which only the two single carbons were burnt, was that it was necessary to make certain the lamp was clean, so as to ensure getting the full value of the reflecting power of the reflector, and all the duty out of the lamp that was possible, provided the ceiling was kept properly white-washed.

The question of candle-power had troubled him a good deal, because he was not responsible for the expression, and confessed he hardly knew what it meant. It was therefore a great relief to hear from Professor Kennedy (page 423) that it was so entirely arbitrary a method of designating a lamp.

With regard to the question of cost, some months had elapsed since the paper had been written, and a good deal more experience had been gained in the interval. Even now however his experience was not yet sufficiently positive for enabling him to state the cost definitely; but as soon as he was able to do so, he would get the actual particulars of the cost of the electric lighting against the previous gas lighting. [See page 431.]

As to the fire risk attending this plan of lighting, he remembered that, when the matter was brought up and dealt with in the north of England by the inspectors and engineers of the insurance companies, one of the arguments made use of was that the chains, the suspension cord, and all the tackle outside the lamp might get covered with fly; and that, if by any accident this got lit by the action of the arc-lamp itself, the fire would be carried as by a train of gunpowder to perhaps a dangerous part. Such an occurrence he must admit did seem feasible on the face of it. But with regard to the dropping of particles of incandescent carbon, no accident could occur, short of the lamp itself breaking down, because as already explained there was no aperture in the bottom part of the conical reflector or in the mechanism of the lamp itself; and it was impossible by any fair means to make a spark come out of the lamp. Even if the incandescent ends of the two carbons were knocked against each other, not a single spark would fly outside the rim of the conical reflector. Cotton fly might be poured into the reflector until it came up to the arc, when it would catch fire and burn down to the bottom of the reflector; but not a spark could be made to go outside the reflector. In this respect therefore there was no danger; and the insurance companies would find the inverted arc-lamp, protected by the conical reflector beneath, was one of the safest lamps that could be used.

In the objection to lighting up large shops from a single centre of electric energy (page 419) he fully concurred; and the difficulty had been felt so much in his own works that they were now arranging a number of what were there called "pilot" lamps. These were placed along the passages here and there, and were lit from a separate small engine not connected with the main circuit. The small engine was always running, and there were from 70 to 80 pilot lamps driven by it, which were sufficient to show light in the passages, and so prevent panic. The plan of taking the current for the pilot lamps from the town supply was a good alternative, and would no doubt answer admirably. An automatic arrangement of switch was necessary when the two plans of lighting were employed together; and something of the same sort as that described was being carried out in his own works by Mr. Parsons, which was not yet finished.

The saw-tooth roof referred to by the President (page 424) was admirably adapted for the plan of lighting by reflection. In spite

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of the apparent loss through the windows, yet, if there was sufficient head-room to place a lamp far enough down the slanting roof, and the ceiling was white-washed, it would be found that almost as much benefit was obtained as if it were a flat ceiling.

The President was sure the members would all agree in passing a hearty vote of thanks to Mr. Dobson for his most useful paper.

Mr. J. Lyons Sampson wrote that he considered the plan adopted by the author was a distinct advance in the important matter of workshop lighting. One of the defects of the electric arc as a source of light is that, as the light is emitted from so small a surface, the shadows are sharp and defined, a small object produces a parallel shadow, and even small floating particles produce long pointed shadows. Light obtained from a large surface is therefore preferable; it shortens the shadows, and renders the transition from light to shade gradual, instead of sudden. On the plan described in the paper the arc light is made partly to fulfil this condition by reflecting its rays from a large white surface. Unfortunately in some workshops a white ceiling cannot be secured. In iron foundries, for instance, it would be impracticable to keep a ceiling white for many days together.

Some time ago, when the writer had to remodel the lighting of a workshop of this description, the difficulty was aggravated by the fact that central lights could not be used on account of the travelling cranes. The plan adopted, which has proved highly satisfactory in regard both to lighting and to cost, is illustrated in Plate 71. The building to be lit is an iron foundry 105 feet long by 39 feet wide; as part of the length is occupied by a drying stove, cupolas &c., the working area to be lit is reduced to 85 feet by 39 feet, Fig. 19. Along the side walls are a row of columns, carrying the gantry on which work two heavy travelling cranes C, Fig. 20, with a head-room of 15 feet beneath. The previous lighting consisted of long arms of gas-pipe with ordinary fish-tail burners, placed about six feet apart and projecting from a gas main running along the gantry. The light from this arrangement was bad, especially in the centre of the foundry; and each moulder had to have an oil lamp for enabling him to finish his work. Large gas lamps on the regenerative principle, which were first tried, gave a better light; but the smoke and dust necessitated constant cleaning, which together with cold draughts rendered the breakage of glass a heavy item. Having seen large flare lamps, burning creosote oil, used successfully in erecting new buildings and for temporary purposes of that nature, the writer determined to try whether they could be arranged to serve for permanent lighting; and selected the Wells plan as most suitable for the purpose.

The burner, Fig. 18, consists of a hollow iron coil, into which creosote oil is forced under a pressure of from 20 to 25 lbs. per square inch. One end of the coil terminates in a small hole, through which when the coil is heated the vapour escapes, and being ignited forms a long brush of brilliant flame; this passes through the centre of the coil, so that, when once lit, the flame supplies the coil with the heat necessary to keep up the supply of vapour. Two of these burners are used, which are placed as shown at BB in Figs. 19 and 20, one on each side of the foundry on long swing brackets, and as high as the travellers C would permit. They are free to swing aside if touched by the traveller chain; and are provided with a slight guard to prevent the chain from fouling the burner. The supply of oil is led to them through a 3-8ths inch gas-pipe, connected to a small air-vessel or pressure-tank P, into which the oil is pumped under a pressure of from 20 to 25 lbs. per square inch. The pump is so arranged that either oil or air can be pumped in, as required; it draws its supply of oil from a larger tank T holding about 1½ ton, in which the oil is stored.

Some difficulty was found at starting, in heating the burners preparatory to lighting them; and various devices were tried. Eventually a large Bunsen burner was fixed to the gas main, in such a position that the coil could be swung over it. About eight minutes is ample to heat the coil; then the oil is turned on, and the gas extinguished. The two Bunsen burners each consume at the rate

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of 30 cubic feet of gas per hour. Owing to the large surface of the brush of oil flame, and to the position of the burners, the effect of the light is so good as to be even better than daylight in the locality in which the foundry is situated; and there is a practical absence of shadows. The size of burner used is said by the makers to give 2,000 candle-power for each burner.

As regards the cost of the plan, the rate per hour cannot be given, because no record has been kept of the lighting hours; but the total cost for three years has been ascertained. During that part of the year when artificial light is required, the lamps are lit at 5 a.m., and extinguished on the average at 6 p.m. In foggy weather they might be kept alight all day; otherwise they would be extinguished in the morning as soon as the daylight becomes bright enough to do without them, and would be lit again in the afternoon as early as required. The total cost of oil for three years ending January 1893 was £60, or £10 per burner per annum. The Bunsen burners add five shillings to the annual cost of each light. As regards the cost of maintenance, the plan was started four years ago with three burners, two in use and one spare. Since then two have been replaced by new burners; they cost about 35*s.* each. The first cost of the air-vessel or pressure-tank P with pump and the three original burners was £20; the storage tank T, swing brackets, Bunsen burners &c., came to about the same amount; hence the total first cost was about £40. In use, a deposit of carbon takes place in the tube of the coil; but as the coil is formed round a square, and has a plug at each corner, the deposit is readily removed by passing a drill through; as this is done by the engine-driver when otherwise unemployed, it has not been taken into account in the cost. By having a spare burner, one is always kept ready to replace either of the other two that may want cleaning. By storing the oil in bulk in the tank T, any impurities in it have time to settle.

Mr. Dobson wrote, respecting the comparative cost of gas and electricity (page 426), that the result of four years' experience shows that with the plan of electric lighting described in the paper remarkably little repair is required; but constant attention is necessary, which if properly bestowed will avoid the necessity of repairs, by keeping all parts of the lamps thoroughly clean. There are now in daily use at his works 120 of these inverted arc-lamps, and preparations are being made for a large addition to this number. In considering the question of cost, it ought to be stated that, as compared with gas, all electric-light installations can be economical only when the light is used for at least five hours a day; because, when gas light is not required, the gas is turned off at the main, and there is no waste and no wages for attendance, and the depreciation as calculated is on a much smaller capital outlay. For electric

Gas Installation.

	£	s.	d.
505 gas jets on ground floor, first floor, second floor, and attic, at 6s.	151	10	0
Gas meter, fixing, and connection	56	3	0
Total capital outlay	207	13	0

	s.	d.
Gas per hour for 505 burners of No. 4 size, each burning 4 cubic feet, at 2s. 8d. per 1,000 cubic feet	5	4½
Depreciation at 5 per cent., and repairs at 4s. 6d. per week	0	2
Cost of Gas per hour	5	6½

Electric Installation.

	£	s.	d.
60 arc-lamps fixed, at £10 each	600	0	0
90 incandescent lamps fixed, at 25s. each	112	10	0
Switch-board and dynamo	285	0	0
Proportion of engine and boiler	760	0	0
Total capital outlay	1,757	10	0

	s.	d.
Carbons per hour for 60 arc-lamps (of 12 ampères and 115 volts) at 1·2 penny per pair lasting 8 hours	0	9
90 incandescent lamps (1,000-hour lamps), at 1s. 3d. each	0	1½
Coal at 7s. per ton, for 80 I.H.P., at 3 lbs. per I.H.P.	0	9
Attendance, oil, &c.	1	0
Depreciation and repairs, at 10 per cent.	1	4
Cost of Electricity per hour	3	11½

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lighting the capital outlay, including the driving power, will be from eight to ten times that of gas; and the depreciation will be calculated whether the apparatus is working or not. In the accompanying figures (page 431), which have been carefully worked out for No. 9 building at the writer's works, the economy of electricity is marked and real, because the nature of the building and the work require constant employment of the electric light.

ON THE WORKING OF STEAM PUMPS ON THE RUSSIAN SOUTH WESTERN RAILWAYS.

BY MR. ALEXANDER BORODIN, ENGINEER-DIRECTOR.

The Steam Pumps employed for the water supply to the stations of the South Western Railways are of various kinds; and in consequence of the growth of the traffic, new pumps, larger and more economical, are constantly having to be procured. With a view to reduce the cost of working and maintenance, a series of experiments were made with the pumps at the principal stations, for ascertaining the cost of the water supply and the useful work performed by the different kinds of pumps, as well as by individual pumps of the same kind working under different conditions. The successive trials have been carried out during the past few years, and are still going on; the results already arrived at however are plain enough to be now made known.

The experiments were all alike conducted in the following manner. Each trial lasted from four to nine hours, during which time observations were made of the fuel consumption, of the boiler feed-water, of the number of strokes of the pump, and of its total delivery; the last was ascertained either by a water meter or by direct measurement of the water level in the supply tanks. At the same time the pressure or head of water in the delivery pipe close to the pump was noted by a pressure gauge, both when the pump was at work, and also when it was standing with the delivery pipe full of water. To the delivery head when at work was added the suction lift, so as to get the total height h in feet to which the water was raised by the pump, including the friction in both pipes. Then the weight in pounds of water w pumped per hour being also known, the horse-power of the useful work done by the pump would be H.P. $= w \times h \div (60 \times 33{,}000)$.

From these observations was determined:—firstly, the weight of water pumped in pounds per pound of steam or rather of feed-water, and per pound of fuel; secondly, the consumption of steam or of feed-water per hour and per useful horse-power; and thirdly, the foot-pounds of useful work performed by the pump per pound of feed-water. Moreover by comparing the volume engendered by the pump with the volume of water delivered during the same time, the efficiency of the pump itself was arrived at. The evaporation per pound of fuel was also determined; and in some cases the consumption of fuel for getting up steam.

The experiments were made by several observers, and with great care, and all necessary precautions were taken. The water level in the boiler was brought back to the same height at the end of the trial as at the beginning. Where the boiler was fed direct from the delivery pipe of the pump, the feed-water was added to the quantity of water delivered into the tank; and no water was drawn off from the tank during the trial. The fuel consumed was accurately weighed. The following pumps were all tried in their ordinary working condition, without any special preparations being made for the trials.

Reschitz Pumps.—These are pumps of old make, as shown in Fig. 1, Plate 72, and were put up twenty years ago at the time of the Odessa line being constructed. They are driven by a horizontal engine with fly-wheel, which through gearing gives a reciprocating movement to a lever; connecting-rods from the lever work the pumps, which are fixed in a well at such a depth as to be always above water. The object of the gearing is to give the pumps a slower piston-speed than the steam piston, because in those early days it was found necessary to work the pumps very slowly. These machines are exceedingly bulky and heavy, taking up a great deal of room, and requiring strong foundations; they are troublesome to erect, and also to maintain.

Cail Pumps.—These are also of old make, as shown in Fig. 2, Plate 72, and are driven by a portable engine with belt pulley, from which the power is taken through a belt and gearing and connecting-rod to a horizontal pump; the centre line of the pump is in the same vertical plane as the centre line of the engine. These machines are still bulkier than the preceding, and take up a good deal of room lengthways; they require costly foundations, and are expensive in maintenance.

Ordinary Pumps and Vertical Engines.—One from the Lilpop Rau Works was put up at Jmérinka in 1878; and another at Kieff at the time of the line being constructed. Where the latter was made is not known.

Cockerill Pumps and Horizontal Engines.—The engines are of good make, with double slide-valves and fly-wheel, as shown in Fig. 3, Plate 73; the pump is either worked direct by the piston-rod of the steam cylinder, or else is driven off the fly-wheel shaft through gearing for reducing the speed of the pump. These are among the more powerful steam-pumps, working on long pipes with great differences of level. Both engines and pumps are well worked out in all their details, and well made; but they are bulky and costly, occupying a large space and requiring expensive foundations.

Pulsometers and Injectors.—Ten or fifteen years ago these appliances were for some time much in vogue, owing to their simplicity, compactness, and cheapness. They are in striking contrast with the heavy and bulky machines already described. In Figs. 4 to 6, Plate 74, is shown a pulsometer in use at Klestchely.

Hayward Tyler Direct-acting Pumps.—These are devoid of fly-wheel or external moving parts, having the pump piston on the same horizontal rod as the steam piston, as shown in Figs. 7 to 9, Plate 75. They are remarkable for their compactness, for the small space they occupy, and for the ingenious distribution of the steam by means of a slide-valve arranged inside the hollow piston of the steam cylinder. They need scarcely any foundation, and can be placed on a lightly fixed beam.

Worthington Ordinary and Compound Pumps, and Blake Compound Pumps.—These pumps of American invention are shown in Figs. 10 to 13, Plates 76 to 78. Like the Hayward Tyler, they are horizontal direct-acting, and remarkable for compactness, for facility of erection, and for the small foundations they need. The Worthington pumps especially, owing to the high speed of the pump pistons, are remarkably light, small, simple, and cheap, in spite of having two steam cylinders and two pumps arranged close to each other; the piston-rod of each pump moves the slide-valve of the steam-cylinder of the other pump. The high speed of the pump piston in the Worthington pumps is in striking contrast with that in the old kind of pumps, in which the pump piston had to be worked at a very low speed. For example, the Reschitz pump at Katerinovka station and the Cockerill pump at Wessiolly Koute station work at only 33·5 and 39·4 feet per minute respectively; whereas the Worthington pump at Krijopol station works at 100 feet per minute, and its maximum speed is still higher. All new pumps that are now being put up on the South Western Railways are exclusively of the Worthington or Blake kind.

Trials.—All the engines tried in these experiments were working without condensation, excepting the Hayward Tyler pumps at Zabolotié station and the Worthington pumps at Birzoula. In these cases however the condensers were inferior; and in the two trials therefore, Nos. 19 and 30 in Table 4 appended (pages 446–9), not much good resulted from condensing the steam. From the principal results observed, which are given in Table 4, the following conclusions may be drawn.

Firstly, the efficiency of the steam expended in raising water for the supply of a railway station depends largely upon the quantity of water supplied per hour; and the greater this quantity, up to a certain maximum limit, the more advantageously does the pump work. Under the conditions of ordinary working Table 1 shows the head in feet against the different pumps, the delivery in gallons per hour and in pounds per pound of steam, and the work in foot-pounds per pound of steam.

TABLE 1.

Work done by Steam Pumps.

Name of Pump, and Head of Water.	No. of Trial.	Station.	Water Pumped.		Work done per lb. of Steam.
			Per hour.	Per lb. of Steam.	
	No.		Gallons.	Lbs.	Ft.-Lbs.
Hayward Tyler. 33 to 46 feet.	18	Zabolotié	2,460	90	2,950
	19	Zabolotié	3,020	101	3,310
	17	Zdolbounovo	3,650	129	5,940
Reschitz. 184 to 207 feet.	7	Elizavetgrad	990	36·1	7,090
	4	Razdelnaia	1,330	47·5	9,840
	3	Golta	2,640	58·5	10,760
Worthington Non-compound. 112 to 131 feet.	27	Demkovka	2,220	102	11,380
	26	Christinovka	3,300	101	11,250
	23	Kazatine	6,890	144	18,900
	21	Zdolbounovo	8,800	152	19,460
184 to 190 feet.	25	Koublitch	2,220	88·5	16,830
	22	Ogénine	6,100	111	20,410
Worthington Compound. 591 feet.	31	Birzoula	9,420	63·4	37,400
Blake Compound. 558 feet.	33	Birzoula	4,030	52·6	29,330

Secondly, the efficiency of the steam depends likewise upon the size of the pumps, which again depends upon the quantity of water delivered per hour as well as upon the height to which it is lifted; and the consumption of steam per useful horse-power diminishes as the work done by the pump increases. This is illustrated in Table 2, which for each of four kinds of pumps gives a comparison of the steam consumption per horse-power per hour in various examples of the same kind.

TABLE 2.

Steam Consumption in Steam Pumps.

Pump.	No. of Trial.	Station.	Useful Horse-Power.	Steam used per H.P. per hour.
	No.		H.P.	Lbs.
Reschitz.	7	Elizavetgrad	0·99	279
	6	Pomoshnaia	1·08	279
	4	Razdelnaia	1·38	201
	5	Shestakovka	1·97	266
	3	Golta	2·47	183
	2	Katerinovka	2·69	114
	1	Zatichié	3·71	145
Worthington Non-compound.	27	Demkovka	1·18	183
	26	Christinovka	1·78	183
	25	Koublitch	2·12	118
	24	Kivertzy	4·04	94
	22	Ogénine	5·62	98
	21	Zdolbounovo	5·67	107
	20	Krijopol	8·19	78
Worthington Compound.	28	Gaicine	3·55	94
	29	Wessiolly Koute	14·7	60
	30	Birzoula	28·4	50
Blake Compound.	36	Razdelnaia	5·13	92
	34	Kazatine	7·89	85
	33	Birzoula	11·3	65

The slight discrepancies noticeable in Table 2 are doubtless owing to accidental causes. The larger consumption of steam per horse-power per hour in the smaller pumps is explained by the well known fact that the useful effect of small engines is less, while the influence of their useless resistances is greater. The same fact explains also the generally large consumption observed in all the steam pumps tried, which ranges in Table 4 from 680 down to 50 lbs. per horse-power per hour.

For comparing the steam consumption in these steam pumps with that of ordinary high-pressure non-condensing engines, which ranges from 30 down to 20 lbs. per indicated horse-power per hour, the useful horse-power in the pump would have to be replaced by the indicated horse-power in the steam cylinder. Unfortunately in the experiments here dealt with no indicator diagrams were taken; and the substitution of the indicated horse-power in the cylinder can therefore be effected only by the aid of observations made on other steam pumps. In Mr. F. Colyer's work on "Pumps and Pumping Machinery" (1882 pages 64–80) a description is given of various experiments on large condensing pumping engines; from which it appears that in steam pumps developing from 100 to 300 horse-power the useful work forms from 72 to 82 per cent. of the indicated horse-power; or inversely, the indicated power exceeds the useful work by 39 to 22 per cent. In trials made of a 78 horse-power pumping engine at Colmar the useful work amounted to 77 per cent. of the indicated power. Doubtless in small pumps, such as those for the supply of railway stations, friction and other useless resistances absorb a large portion of the power developed in the steam cylinders; and the smaller the pump, the greater is this loss. Experiments made in England on a small engine in a mechanical laboratory show that with 10·53 and 14·29 indicated horse-power the corresponding brake horse-power was 6·85 and 10·60 respectively: that is, the indicated exceeded the brake horse-power by 54 to 35 per cent. ("Engineering" 25 Dec. 1891 page 744). On the other hand, in direct-acting non-condensing steam-pumps, without any revolving shaft or connecting gear—such as the Worthington, Blake, and other pumps—the internal resistances are less than in the more complicated condensing engines having fly-wheels and connecting gear for driving the pumps; thus according to experiments made by Messrs. Mair and Simpson on a Worthington pump developing nearly 100 horse-power, the useful work even reached as much as nearly 90 per cent. of the indicated power. It will probably be not far from correct to assume that in the Worthington compound pump at Birzoula (trial 30) developing 28·4 useful horse-power the indicated horse-power was 40 per cent. higher, amounting to 40 horse-power: in which case the consumption of 50 lbs. of steam per useful horse-power will be equivalent to 36 lbs. per indicated horse-power. If that be so, it would seem that even the best and most powerful pumps for the supply of railway stations—such as the Worthington pump among those here dealt with—may require from 40 to 50 per cent. more steam than modern non-condensing engines. In the rest of the pumps tried, the steam consumption was considerably greater still.

It will further be seen how far the small pumps employed at railway stations are inferior in efficiency to the large pumping engines used for mines or waterworks. In the best Cornish and other pumping engines Mr. Colyer states that one cwt. of good English coal produces a duty of from 94 to 112 million foot-pounds of work. Assuming that one pound of coal, burnt under favourable conditions of boiler firing, will evaporate as much as 10 pounds of water, it follows that one pound of steam will produce from 84,000 to 100,000 ft.-lbs. of work. Now the most economical of the steam pumps already described, namely the non-condensing Worthington compound at Birzoula, gives only 37,400 ft.-lbs. of useful work per pound of steam, or $2\frac{1}{2}$ times less than the best pumping engines of large size. The latter it is true are all condensing engines; yet when the same Worthington pump was worked condensing, though with an inferior condenser, its duty was increased only to 39,700 ft.-lbs. per pound of steam. The rest of the steam pumps gave still less economical results. It may be observed that waterworks pumping engines fall far short of the duty of Cornish engines; thus the engines recently erected at Samara yield a duty of only 51,600 ft.-lbs. per pound of steam, instead of 100,000 ft.-lbs.

Thirdly, when the results of the present experiments are classified according to the several kinds of pump employed, the following conclusions are arrived at.

a. The least economical in steam consumption are the injectors, and next to them the pulsometers. The injectors tried are at least $84{,}000 \div 1{,}310 = 64$ times inferior to the Cornish pumping engine, and the pulsometers $84{,}000 \div 2{,}300 = 37$ times. This arises neither from their small size nor from the small depth from which they can draw by suction; but from the very nature of their construction, in consequence of which the heat of the steam is largely wasted in uselessly heating the water lifted. Practically the useful effect of injectors and other similar appliances does not depend at all on their size or on the quantity of water they deliver; as the height to which they deliver increases, their efficiency, unlike that of other steam pumps, falls lower and lower, and soon reaches a minimum, below which they are no longer of any use for raising water. Although in this respect the pulsometer is much better than the injector, yet even under the most favourable circumstances it requires a boiler two or three times larger than would be needed for a steam engine; and as pumps of such simple make can now be had so cheap, there is no longer any need to have recourse to these kinds of appliances, not even on account of their costing less to put up. Appliances of these kinds can be used only in exceptional cases, where the cost of fuel is of no consequence, or where there is more steam than is wanted, or where there is no room and no time to put up a steam pump; or indeed where the water is wanted to be heated, so as to be used for instance as feed-water, in which case these appliances, though otherwise most wasteful, may prove distinctly economical.

b. The next pumps of low economy are the Hayward Tyler. In regard to these it must be mentioned that the one at Zabolotié station which shows a particularly low efficiency is among the number of those that have already become worn by use; the original pistons and slide-valves have been replaced by others made on the spot, and it is quite possible that the original dimensions and the arrangement of the steam ports may have been altered, however slightly; the working would be all the more affected by any such alteration, owing to the complicated shape of the pistons and slide-valves, which require to be finished with the greatest accuracy. A pump of the same kind at Zdolbounovo station worked much better, and fell but little short of the Reschitz pumps of small size; it gave 5,940 ft.-lbs. per pound of steam, in comparison with 7,050 ft.-lbs. from the lowest Reschitz pump.

c. The steam pumps in most extensive use cannot easily be arranged in order of useful effect, for want of sufficient accuracy in the trials, as well as owing to the great diversity of the conditions under which they work, in regard to height of lift, quantity of water raised, and state of repair of the pumps themselves. The Reschitz pumps however are in all cases at the bottom of the scale; their maximum efficiency at Pomoshnaía, Elizavetgrad, Shestakovka, and Razdelnaia was not more than from 7,050 to 9,840 ft.-lbs. per pound of steam (trials 4–7). But this may be partly explained by their being so small, developing less than 2 horse-power. The larger pumps of the same kind at Zatichié and Katerinovka yielded a useful effect of 13,620 to 17,390 ft.-lbs. (trials 1–2). It is evident that, as the power of a pump diminishes, a larger proportion becomes absorbed by the resistances; and in pumps of very low power, such as only 1 to 3 horse-power, the power absorbed by internal resistances and by loss of heat is much greater than the useful work. Nevertheless on comparing, for instance, the Reschitz pump at Zatichié (trial 1) with the Worthington compound at Gaicine (trial 28) of about the same power, it appears that, while the work of the former was only 13,620 ft.-lbs. per pound of steam, that of the latter was 56 per cent. greater, amounting to 21,200 ft.-lbs.

The three following pumps produced generally a larger amount of useful work than the foregoing. The ordinary Worthington pumps rose to 21,460 ft.-lbs. per pound of steam at Kivertzy station (trial 24), and that at Krijopol station to 25,690 ft.-lbs. (trial 20); the latter is of large size and of American make, while the others are from the Liszt works, Moscow. The Blake compound pumps rose to 29,330 ft.-lbs. at Birzoula station (trial 33). The Worthington compound at the same station gave 37,400 ft.-lbs. when non-condensing (trial 31), and 39,700 ft.-lbs. when condensing (trial 30). The comparatively high results obtained from this pump, it should be observed, are to be ascribed not merely to the excellence of the class it represents, but also to its large size; it delivers 9,460 gallons per hour to a height of 591 feet, and develops more than 28 horse-power. It should also be observed that the saving of 6 per cent. due to the condenser is not as much as was expected, owing to the condenser being itself defective.

Fourthly, where a pump of one kind was replaced by another of a different kind at the same station, a comparison can be made of the results obtained with the old and the new pump, in water raised per pound of steam, and in efficiency or foot-pounds of work done. This comparison is shown in Table 3.

TABLE 3.

Comparison of Work done by old and new Pumps.

Station.	No. of Trial.	Old and New Pumps.	Water Pumped per lb. of Steam.	Work done per lb. of Steam.
	No.		Lbs.	Ft.-lbs.
Razdelnaia	4	Old Reschitz pump	47·5	9,840
	36	New Blake compound	95·8	21,460
Krijopol	8	Old Cail pump	89·5	21,130
	20	New Worthington ordinary	103	25,690
Wessiolly Koute	13	Old Cockerill pump	39	24,940
	29	New Worthington compound	46	32,810
Zdolbounovo*	17	Old Hayward Tyler	129	5,940
	21	New Worthington ordinary	152	19,460
Birzoula	33	Blake compound pump	52·6	29,330
	31	{Worthington compound without condensation}	63·4	37,400

* Simultaneously with the change of pumps the source of supply was also changed, whereby the gross head against which the pump worked was increased from 46 feet up to 128 feet, including the friction in the pipes.

The superiority however of the newer kinds of pumps to the older will not follow directly from this comparison; for all the newly erected pumps, being designed for a larger quantity of water than the pumps they superseded, should on that very account be more economical. The consumption of fuel per gallon of water raised at these stations fell off in proportion to the increased efficiency shown by the figures in Table 3.

Fifthly, it is interesting to compare with the results observed on the South Western Railways those obtained elsewhere by other observers as to the performance of pumps. Some of the principal may therefore be quoted in conclusion.

In the Journal of the Society of German Engineers (1886, page 16) is briefly quoted the comparative fuel consumption in raising water by means of a pulsometer, and of steam pumps both ordinary and compound condensing; the results in the three cases are in the ratio 20 : 10 : 4. The consumption of twice as much fuel with the pulsometer as with the ordinary pumps agrees with the foregoing experiments. But as for the consumption with an ordinary steam-pump being reduced in the ratio of 10 to 4 by altering the engine to compound condensing, it appears to the writer that such a statement greatly exaggerates the actual saving.

In the Journal of the Franklin Institute (Oct. 1889 pages 276–293) are published some interesting experiments by Mr. Isherwood, engineer-in-chief of the United States navy, on the comparative work done by an ordinary steam-pump, by a rotary pump driven from the fly-wheel of the ordinary steam-pump, and by an injector. All three were employed during the trial in pumping out the bilge-water of a vessel and delivering it to a height of 17 feet 8 inches. Their deliveries per hour were—ordinary pump 4,520 gallons, rotary pump 3,920 gallons, and injector 2,530 gallons. In comparing these with the corresponding results from the pumps at Zabolotié (trials 18–19) and the injector at Klestchely (trial 16), it will be noticed that the quantity of water is greater in the former, but the height of lift is less. Mr. Isherwood's experiments lasted from 24 to 72 hours, and were made with the greatest care, and the chief results were as follows:—

		Ordinary Pump.	Rotary Pump.	Injector.
Working Head, including friction, .	feet	17·67	17·67	17·67
Delivery per hour, ...	gallons	4,520	3,920	2,530
Useful Effect, . . .	per cent.	86	58	—
Boiler pressure above atm.,	lbs. per sq. inch	30	30	30
Water raised per lb. of steam, . .	lbs.	136	109	37·4
Work done per lb. of steam, . .	ft.-lbs.	2,400	1,920	660

Thus the work done per pound of steam by the pumps and injector was rather less than at Zabolotié and Klestchely stations, which is accounted for by the considerably lower head in Mr. Isherwood's experiments. In both experiments alike the injector was low in economy. The inferiority of the rotary pump to the ordinary pump with flap-valves was probably owing to leakage of water past the revolving pistons.

In the Proceedings of the Mulhouse Society (1889 page 151) the results of trials of a Tangye pump are quoted by M. Walther-Meunier. This pump belongs to the class of direct-acting pumps without fly-wheel, like the Hayward Tyler. In the trials quoted it raised nearly 800 gallons of water per hour to a height of 36·7 feet. It thus compares with the pump at Zabolotié (trial 18), though of smaller size than the latter. The best results obtained in the series of trials with this pump were as follows:—

Working Head, including friction	36·7	feet.
Delivery per hour	797	gallons.
Boiler pressure above atm., lbs. per sq. inch	42·7	lbs.
Useful Work, horse-power	0·148	H.P.
Water raised per lb. of steam	63	lbs.
Weight of Steam used per H.P. per hour	855	lbs.
Work done per lb. of steam	2,316	ft.-lbs.

These results are sensibly accordant with those obtained at Zabolotié, and the lower useful effect is due to the smaller size of the Tangye pump.

TABLE 4 (*continued to page* 449).

Trials of Steam Pumps

Pump. *See Plates* 72 *to* 75.	No. of Trial.	Station.	FUEL. Description.	FUEL. Consumption per hour.	Boiler pressure above atmosphere. Lbs. per square inch.
	No.			Lbs.	Lbs.
RESCHITZ. *Plate* 72, *Fig.* 1.	1	Zatichié	Donetz Coal	88·4	40
	2	Katerinovka	Do.	46·5	40
	3	Golta	Do.	86·9	45
	4	Razdelnaia	Cardiff Coal	—	45
	5	Shestakovka	Coal	79·8	45
	6	Pomoshnaia	Donetz Coal	46·7	22
	7	Elizavetgrad	Do.	59·5	22
CAIL. *Plate* 72, *Fig.* 2.	8	Krijopol	Firewood of different kinds.	134·0	55
	9	Fastov		97·0	35
VERTICAL, Lilpop Rau Works.	10	Jmérinka		341·7	45
VERTICAL, origin unknown.	11	Kieff		86·0	40
COCKERILL. *Plate* 73, *Fig.* 3.	12	Perecrestovo	Donetz Coal	134·9	60
	13	Wessiolly Koute	Do.	96·6	60
	14	Karpovo	Do.	88·2	35
PULSOMETER. *Plate* 74, *Figs.* 4–6.	15	Klestchely	Deal Wood	163·1	60
INJECTOR.	16	Klestchely	Do.	178·6	60
HAYWARD TYLER. *Plate* 75, *Figs.* 7–9. Without condensation.	17	Zdolbounovo*	Oak Wood	109·1	50
	18	Zabolotié (worn)	Do.	122·6	50
With condensation, but condenser inferior.	19	Zabolotié (worn)	Do.	136·0	50

* At Zdolbounovo until 1891 the feed-water was supplied since 1891 it has been obtained from a

(*continued from opposite page*) TABLE 4.

for Water Supply of Railway Stations.

STEAM CONSUMED.			Speed of Pump. Double strokes or Revolutions per minute.	Useful effect of Pump.	Gross height of Lift, including pipe friction.	WATER RAISED.			WORK DONE.	
Per hour.	Per horse-power per hour.	Per pound of fuel.				Per hour.		Per pound of steam.	Horse-power.	Per pound of Steam.
Lbs.	Lbs.	Lbs.	Revs.	P. c.	Feet.	Galls.	Lbs.	Lbs.	H. P.	Ft.-Lbs.
540	145	6·10	13·6	76	397	1,850	18,500	34·3	3·71	13,620
306	114	6·53	13·1	—	328	1,620	16,200	53·0	2·69	17,390
452	183	5·20	14·3	78	184	2,640	26,400	58·5	2·47	10,760
280	201	—	13·0	—	207	1,330	13,300	47·5	1·38	9,840
525	266	6·58	13·2	70	256	1,530	15,300	28·1	1·97	7,190
304	279	6·50	18·0	71	210	1,020	10,200	33·5	1·08	7,050
276	279	4·90	17·0	78	197	990	9,900	36·1	0·99	7,090
373	94	2·78	20·3	80	236	3,320	33,200	89·5	3·97	21,130
254	134	2·40	14·6	97	128	2,820	28,200	120	1·87	15,360
1,146	139	3·35	29·8	70	361	4,600	46,000	38	8·41	13,710
313	132	3·60	21·5	90	919	4,970	49,700	164	2·42	15,060
747	81	5·50	10·9	81	604	3,020	30,200	40·4	9·21	24,380
650	78	6·73	9·6	80	640	2,530	25,300	39	8·19	24,940
562	107	6·38	11·3	77	472	2,180	21,800	38·9	5·21	18,050
364	860	2·23	—	—	38	2,200	22,000	61	0·42	2,300
397	1,440	2·23	—	—	38	1,410	14,100	35	0·28	1,310
284	310	2·58	84·4	76	46	3,650	36,500	129	0·92	5,940
276	680	2·24	99·4	—	33	2,460	24,600	90	0·40	2,950
298	600	2·19	103·7	—	33	3,020	30,200	101	0·49	3,310

from a well situated in the station by means of a Hayward Tyler pump;
stream by means of a Worthington pump.

TABLE 4 (*continued from preceding page*).

Trials of Steam Pumps

Pump. *See Plates* 76 *to* 78.	No. of Trial.	Station.	FUEL.		Boiler pressure above atmosphere. Lbs. per square inch.
			Description.	Consumption per hour.	
	No.			Lbs.	Lbs.
† from America.	20	Krijopol †	Donetz Coal	86·9	70
	21	Zdolbounovo*	Deal Wood	166·2	—
Worthington Ordinary, from Liszt Works, Moscow.	22	Ogénine	Firewood	151·0	70
	23	Kazatine	Do.	151·9	60
	24	Kivertzy	Do.	106·7	60
	25	Koublitch	Donetz Coal	38·6	60
Plate 76, *Figs.* 10–11.	26	Christinovka	Do.	50·9	75
	27	Demkovka	Do.	28·0	55
Worthington Compound. *Plate* 77, *Fig.* 12.	28	Gaicine	Do.	51·6	75
	29	Wessiolly Koute	Do.	126·8	60
With condensation, but condenser inferior.	30	Birzoula	Coal	242·5	80
With heating and without condensation.	31	Birzoula	Do.	260·1	80
Without heating and without condensation.	32	Birzoula	Do.	275·6	80
Blake Compound from Owens Works.	33	Birzoula	Donetz Coal	—	80
	34	Kazatine	Firewood	207·7	60
	35	Kazatine	Do.	162·0	60
Plate 78, *Fig.* 13.	36	Razdelnaia	Cardiff Coal	—	60

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* At Zdolbounovo until 1891 the feed-water was supplied since 1891 it has been obtained from a

(*concluded from page* 446) TABLE 4.

for Water Supply of Railway Stations.

STEAM CONSUMED.			Speed of Pump. Double strokes or Revolutions per minute.	Useful effect of Pump.	Gross Height of Lift, including pipe friction.	WATER RAISED.			WORK DONE.	
Per hour.	Per horse-power per hour.	Per pound of fuel.				Per hour.		Per pound of Steam.	Horse-power.	Per pound of Steam.
Lbs.	Lbs.	Lbs.	Revs.	P. c.	Feet.	Galls.	Lbs.	Lbs.	H.P.	Ft.-Lbs.
633	78	7·28	60	83	249	6,510	65,100	103	8·19	25,690
604	107	3·62	50	88	128	8,800	88,000	152	5·67	19,460
551	98	3·65	50	89	184	6,100	61,000	111	5·62	20,410
478	105	3·15	60	85	131	6,890	68,900	144	4·58	18,900
375	94	3·50	50	85	141	5,680	56,800	152	4·04	21,460
251	118	6·50	50	85	190	2,220	22,200	88·5	2·12	16,830
326	183	6·40	50	85	112	3,300	33,000	101	1·78	11,250
216	183	7·75	50	83	112	2,220	22,200	102	1·18	11,380
333	94	6·45	50	82	322	2,190	21,900	65·9	3·55	21,200
895	60	7·03	31·4	97	715	4,070	40,700	46	14·7	32,810
1,429	50	5·88	86	90	591	9,550	95,500	67·1	28·4	39,700
1,486	53	5·73	85	90	591	9,420	94,200	63·4	28·0	37,400
1,587	56	5·74	85	90	591	9,460	94,600	59·7	28·3	35,270
765	65	—	20	86	558	4,030	40,300	52·6	11·3	29,330
666	85	3·20	26	—	141	11,000	110,000	166	7·89	23,590
516	89	3·18	20	91	135	8,410	84,100	163	5·76	22,080
474	92	—	18·2	—	223	4,530	45,300	95·8	5·13	21,460

from a well situated in the station by means of a Hayward Tyler pump;
stream by means of a Worthington pump.

TABLE 5.—*Dimensions of Steam Pumps in Table* 4.

Pump. *See Plates* 72 *to* 78.	No. of Trial.	Station.	Steam Cylinder.		Pump.	
			Diameter.	Stroke.	Diam.	Stroke.
	No.		Inches.	Inches.	Inches.	Inches.
RESCHITZ. *Plate* 72, *Fig.* 1.	1	Zatichié	10·62	15·75	4·61	12·60*
	2	Katerinovka	10·62	15·75	4·61	12·60*
	3	Golta	10·62	15·75	5·91	18·90*
	4	Razdelnaia	10·62	15·75	4·61	12·60*
	5	Shestakovka	10·62	15·75	4·61	12·60*
	6	Pomoshnaia	10·62	15·75	4·61	12·60*
	7	Elizavetgrad	10·62	15·75	4·61	12·60*
CAIL. *Plate* 72, *Fig.* 2.	8	Krijopol	6·30	10·62	6·22	14·77*
	9	Fastov	6·30	10·62	6·38	15·75*
VERTICAL, Lilpop Rau Works.	10	Jmérinka	13·58	11·00	5·36	11·00*
VERTICAL, origin unknown.	11	Kieff	8·07	12·60	6·15	19·69*
COCKERILL. *Plate* 73, *Fig.* 3.	12	Perecrestovo	16·34	29·13	6·00	29·13*
	13	Wessiolly Koute	13·00	30·00	6·00	30·00*
	14	Karpovo	11·00	23·93	5·50	23·93*
HAYWARD TYLER. *Plate* 75, *Figs.* 7–9.	17	Zdolbounovo	7·00	7·09	6·00	7·09
	18–19	Zabolotié	7·00	7·09	4·00	7·09
† from America.	20	Krijopol†	9·00	10·00	4·50	10·00
	21	Zdolbounovo	7·50	10·00	5·50	10·00
WORTHINGTON ORDINARY, from Liszt Works, Moscow.	22	Ogénine	7·50	10·00	4·50	10·00
	23	Kazatine	7·50	10·00	4·50	10·00
	24	Kivertzy	7·50	10·00	4·50	10·00
	25	Koublitch	6·25	6·00	3·62	6·00
Plate 76, *Figs.* 10–11.	26	Christinovka	6·25	6·00	4·50	6·00
	27	Demkovka	6·25	6·00	3·62	6·00
WORTHINGTON COMPOUND. *Plate* 77, *Fig.* 12.	28	Gaicine	5·25 10·50	6·00	3·62	6·00
	29	Wessiolly Koute	10·00 16·00	10·00	4·50	10·00
	30–32	Birzoula	8·12 15·75	10·00	4·50	10·00
BLAKE COMPOUND. *Plate* 78, *Fig.* 13.	33	Birzoula	8·00 16·00	23·42	5·50	23·42
	34–35	Kazatine	8·00 16·00	23·42	15·75	23·42
	36	Razdelnaia	8·00 16·00	23·42	5·50	23·42

* Nos. 1 to 14 were geared pumps, and the respective ratios of the number of strokes made by the engine to the number made by the pump were as follows :—Ratio 3·2 to 1 in Nos. 1 to 7 ; 8·63 to 1 in No. 8 ; 8·41 to 1 in No. 9 ; 1 to 1 in Nos. 10 and 12 ; 4·5 to 1 in No. 11 ; 3·29 to 1 in No. 13 ; and ratio 3 to 1 in No. 14.

Discussion.

The President explained that the author of the paper unfortunately was not present, being unable to come from Kieff to England to attend the meeting.

Mr. Robert S. Lloyd was sure that all interested in the paper now read were much obliged to the author for his careful analysis of the various results he had obtained. The field of inquiry he had entered upon was one in which it was difficult to obtain definite results as to the consumption of steam in the working of direct-acting steam-pumps; and the results which he had obtained he had certainly treated with great fairness. Comparisons had been made of a large number of direct-acting pumps obtained from various makers, much to the disadvantage of some of them; but no irritation could be felt, seeing that the subject had been treated with such candour and fairness. Some of the results obtained he wished to analyse, especially with regard to the Hayward Tyler pumps (trials 17-19), with which he was himself concerned. In order to draw comparisons between pumps of different makes, as to their useful effects, the pumps should of course be approximately of the same size, and doing about the same duty. So far as the size was concerned, he could not tell exactly what was the size of the pumps referred to at Zabolotié (trials 18-19); but he found that in 1875 his firm had supplied to the South Western Railways of Russia a double-acting pump of the "Universal" type, with steam cylinder 5 inches diameter and pump 4 inches diameter, which would fairly well accord with the pump reported in the paper. In comparing this with the Worthington pump (trials 20-27), it must be remembered that the latter had about double the capacity, and had also a lift of never less than 112 feet, whereas the Hayward Tyler pump (trials 18-19) had a lift of only 33 feet. Therefore the useful effect of the steam would naturally be much less in the Hayward Tyler than in the Worthington. The simple formula

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employed by his own firm for determining the height of lift for which any of their direct-acting steam-pumps was suitable was the following:—gross height of lift in feet including friction $= 1\cdot735 \times P \times \frac{A}{a}$, where P represented the steam pressure in lbs. per square inch above the atmosphere, A the area of the steam cylinder, and a that of the pump. For a full comparison the pump at Zabolotié with 50 lbs. steam pressure should therefore have worked against a head of not under $1\cdot735 \times 50 \times 25 \div 16 = 135$ feet, instead of only 33 feet, and then the result would have been greatly different. There was also the fact which the author had clearly stated that the Hayward Tyler pump at Zabolotié had been renovated by native hands; its vitals had been taken out and put in again, and how they had been put in again no one knew. Some careful experiments had been made by his firm a few years ago with regard to economy in direct-acting steam-pumps; and certainly the economy obtained by the author with the Worthington pump was higher than he himself had ever been able to obtain with the direct-acting pump without condensation. An experiment extending over a fortnight, with a direct-acting pump having a 12-inch steam cylinder and a 6-inch pump, vertical suction 10¼ feet and vertical delivery 93 feet, making 103¼ feet total lift, gave 12,555 foot-pounds per pound of steam: which, considering that the pump was working with a lift of 103¼ feet as against a lift of 112 feet, would compare not unfavourably with the result of 11,250 foot-pounds given in trial 26 by the Worthington pump; it would have done better if working with a lift of 200 to 250 feet. It was impossible however to compare a pump which had been working for a number of years with a new pump of today. In page 436 it was stated that the Worthington pump at Krijopol station worked at 100 feet per minute: as though that were a high piston-speed. Most pump makers at the present time he thought would not be afraid to run their direct-acting pumps at 100 feet per minute, and probably a great deal more: so that exclusive credit could not be given to the American makers for having improved steam-pumps during the last twenty years. The present cost of the Hayward Tyler pump with 5-inch steam cylinder and 4-inch pump was about £18, while that of the Worthington pump with which it was compared in the paper he imagined would probably be about three times as much. Moreover the Hayward Tyler pump had only two working parts, excluding the valves, whereas the Worthington pump had twelve working parts: so that the economy in repairs, and the effect of many years' work on the two pumps, would be rather to the advantage he thought of the Hayward Tyler pump.

Mr. Druitt Halpin considered the author had rendered valuable service by collecting in his paper a number of data which could not be found in any other way. As the names of the stations at which the several pumps were working did not sound familiarly to foreign ears, he suggested the numbering of the trials from 1 to 36 in the several tables, for greater convenience of reference. In page 439 it was stated that unfortunately in the experiments here dealt with no indicator diagrams had been taken; and he had himself therefore the pleasure of furnishing the two pairs of sample diagrams shown in Figs. 14 to 17, Plate 79, which were taken from the steam cylinder and pump of a duplex direct-acting steam-pump, but not a Worthington pump. In these diagrams the horizontal length, instead of representing as usual the stroke alone, was drawn to represent also the relative areas of the steam and pump cylinders, in order that each pair of diagrams might show at a glance the ratio of the indicated horse-power to the water horse-power, the actual length of stroke being the same in the steam and pump cylinders in all duplex pumping engines. The great drop in the steam line could not be avoided, because at the time when the tests were made the boiler happened to be supplying this one pump only. The boiler was unfortunately too large for the work, so that it was difficult to keep the evaporation down to the low rate requisite for working the pump; in fact the fire had to be continually damped with ashes, in order to keep the pressure down even to the level shown. The back pressure in these diagrams showed what was due to the engine working through feed-heaters for heating the feed-water. The actual mean figures for the whole trial were as follows. The steam pressure in the boiler was 44 lbs. per square inch above the atmosphere; the diameter of the steam cylinder was 7 inches, and

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of the water cylinder 5 inches, with 9 inches stroke, making 34 double strokes per minute, which gave 51 feet per minute as the piston speed. The rising main was 3 inches diameter with many bends; and the water was lifted 86 feet 2 inches, for which height the calculated pressure was 37·3 lbs. per square inch. The static pressure observed by the gauge when the pump was standing was 38 lbs., which showed that the gauge must have been pretty nearly right. The indicated horse-power was 2·16, and the water horse-power 1·95, giving an efficiency of 90·3 per cent. for the whole machine. The water slipped was 5·6 per cent., as determined by the counter. The trial was continued over six hours, and the water lifted was measured. The boiler was fed from the waterworks through a Schönheyder meter, by which the feed-water was accurately measured; and the coal was also measured. The feed-water came to 125 lbs. per hour per indicated horse-power and 138 lbs. per water horse-power, showing that the boiler was far too big; it was a Cornish boiler, 5 feet diameter and 15 feet long, with flue 2½ feet diameter. The grate area was 10 square feet; and there were about 247 square feet of heating surface, evaporating at the time about 270 lbs. of water per hour, or only a little over one pound per square foot per hour, which of course was ridiculous. The coal consumption on the other hand was only 2·62 lbs. per hour per square foot of grate; and the evaporation was therefore a little over 10 lbs. per pound of coal.

Mr. William Schönheyder agreed with what had already been said respecting the great value of the results given, as he did not know where else they could be found, especially with regard to the pumps of smaller size, upon which experiments were hardly ever made. Besides numbering the trials consecutively, it would be an advantage if general diagrams of the several kinds of pumps tried could be furnished by the author in illustration of the descriptions of their construction. One inference to be drawn from the paper he thought was that cheap pumps should not be bought except under special circumstances of working convenience; but where the power was not small, their use should be avoided. A good many pumps of that kind had been adopted, both in this country and abroad, which in his opinion ought not to have been employed; and he was certain that, if it had been known at the time that they were so uneconomical as the paper showed them to be, they would never have been used.

With respect to the Hayward Tyler pumps referred to in trial 19, it was stated in page 436 that the condensers were inferior; and it was remarkable how many bad condensers were met with. It seemed to be thought that it was possible to make the air bubble up or down through the water, in whatever direction it was wanted to go, according to the construction of the pump. At some waterworks near London, where one of these direct-acting pumps was being used continuously without any idea of its want of economy, there was also a so-called condensation by means of a surface-condenser with a small horizontal air-pump, which however produced but little vacuum. Only recently in a paper read before the Cleveland Institution of Engineers by Mr. Tom Westgarth (Proceedings 20 April 1893, page 137) an illustrated description had been given of alterations made in an engine at the Newport Iron Works, Middlesbrough, for converting it from non-condensing to condensing; from which it appeared that no better vacuum than 24 inches of mercury was got with the air-pump employed, owing in his own opinion to its being altogether wrongly constructed. Another curious instance, recently illustrated in a German paper,* was that of a large engine in the Chicago Exhibition, having an air-pump with condenser attached, where the air was evidently intended to travel down through the water, which of course it would not do; the result must necessarily be a poor vacuum, and though he understood it was 26½ inches of mercury, yet even this seemed impossible under the circumstances. It was not at all uncommon to see such air-pumps, whereby of course the efficiency of the engines to which they were attached was much reduced.

Mr. Jeremiah Head, Past-President, concurred in thinking that it would much facilitate the full appreciation of the paper if

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* Zeitschrift des Vereines deutscher Ingenieure, 1 July 1893, page 759. Figs. 39 and 40. "Engineering," 8 December 1893, page 695.

(Mr. Jeremiah Head.)

skeleton sketches were given of the different kinds of pumps dealt with. Perhaps one of the most common forms of small steam-pumps used in this country was that introduced by Mr. Cameron of Manchester, a single-acting plunger-pump with the steam cylinder acting vertically downwards upon the plunger. Familiar though he was with it, yet in the absence of sketches of the pumps tried, he could not make out whether the Cameron pump was included among them or not; it was not mentioned by name in the paper.

Mr. J. Eliot Hodgkin said that, although the experiments described in the paper had evidently been carried out in a perfectly fair and straightforward manner, he agreed with the comments already made by Mr. Lloyd (page 451) upon the results obtained, which for the pulsometer were probably even more wide of the mark than for the Hayward Tyler pumps. For example, the weight of steam consumed by the pulsometer per horse-power per hour was given as 860 lbs. in trial 15, Table 4 (page 447). There were however a large number of German imitations of the English pulsometer, and he thought the probability was that the pulsometer tried at Klestchely was not of English make, inasmuch as the consumption quoted was utterly at variance with the results obtained at the present time from any ordinary pulsometer in his own experience, even under the most trying circumstances. Although there had long been inaccurate ideas respecting the performance of the pulsometer, he had not hitherto thought it worth while to take much trouble to dispel them. But in view of the present paper, and in order that a little light might be thrown on this matter, and that the pulsometer, especially in its most modern form, might be somewhat better appreciated than it appeared hitherto to have been, he had asked Professor Beare, of University College, to make a trial of one of the most recent pulsometers with the Grel controlling valve, not under fancy conditions, but under ordinary conditions of working, with an unlagged vertical boiler standing in an open yard, and an unlagged steam-pipe 62 feet long to the pulsometer. The mean boiler-pressure was 55 lbs. per square inch, and the feed 361 lbs. per hour. The measured height of lift was 73 feet, or by pressure-gauge 84·4 feet including friction. The water pumped was 5,738 gallons per hour, which against the head of 84·4 feet represented 2·45 horse-power. The result therefore was that, instead of the 860 lbs. weight of steam given in trial 15, the actual consumption was only 148 lbs. weight of steam per horse-power per hour, and the work done was 13,415 foot-pounds per pound of steam, which compared favourably with what would be expected of an ordinary direct-acting pump, whether a duplex pump or any other of the numerous modifications of the direct-acting pump. A recommendation had been made (page 454) not to buy cheap pumps. But when the pulsometer would give a duty as good as that obtained in the trial just made, in combination with the remarkable facilities and conveniences which it was so well known to possess, it would be seen that, taking into consideration the low first cost, it was indeed highly economical.

In the new Grel arrangement, shown in vertical section half full size in Fig. 18, Plate 80, the steam, instead of being allowed to follow the water through the entire length of a stroke, was now cut off at about half stroke, and the remainder of the stroke was performed by its expansion. For this purpose there was added above the usual ball B a cut-off valve V, in the form of an inverted cup-shaped piston working in a shallow cylinder C; the ball and valve might thus be said to correspond with the main and cut-off valves in an expansion gear; and both were actuated solely by the differences between the pressures inside and outside the top chamber in which they worked. The interior of the cylinder C communicated with the chamber through a small hole J at bottom; and there was a corresponding small hole through the centre of the piston or valve V. Steam being turned on opened the valve V, and flowing through past the ball B into one of the two water-vessels partly drove out the water. When about half the water had been discharged from the emptying vessel, the pressure inside the cylinder C would be sufficient to lift the valve V up against the steam inlet, as shown dotted in Fig. 18, and to keep it closed until the distributing ball B had rolled over to close the mouth of the emptying vessel, thereby allowing the remainder of the stroke to be finished by the expansion of the steam shut in the vessel. This action went on automatically,

(Mr. J. Eliot Hodgkin.)

the expansion valve V admitting and cutting-off steam alternately to the water-vessel left open by the ball B. It was evident that this arrangement entirely precluded the possibility of live steam blowing straight through into the rising main at the end of each stroke, as had been found to occur sometimes in badly designed vacuum-pumps.

As to the reason why the pulsometer, acting expansively, might be expected beforehand to be fairly economical, it would be borne in mind that in a small direct-acting pump a large amount of the power used was consumed in friction. In a duplex pump, say with 6 inches working stroke, there would be when working under pressure probably half an inch clearance at each end of the stroke. There would thus be as much as one-seventh of the steam clean gone to begin with, without allowing for what was also lost in the large double ports. There would also be no expansion, and the exhaust would escape at high pressure into the atmosphere. With the improved pulsometer tried in the test just made, the automatic valve cut off the steam before the end of the stroke, and thus allowed the steam to work expansively. There was no exhaust wasted, because the steam was condensed inside the vessel, and thus created a vacuum to draw the water into it. There was also no friction of moving parts. On the other hand it might be argued that, as the steam came into direct contact with the cold water, condensation would take place, and there would be a loss from this cause. No doubt some steam was lost in this way, but not nearly so much as would be imagined; for a thin film of water having been heated at the surface, there was little time for the heat to be conducted away downwards, because the vessel was emptied so quickly by the steam pressure. In the larger sizes of other direct-acting pumps the poor economy was of course not so manifest as in the smaller sizes, which were too small to work expansively at all; whereas with the pulsometer the Grel arrangement of expansive working could be employed with comparatively small sizes, giving the same economy as in larger. It must further be borne in mind that with the pulsometer no oil or packing was required, and that the repairs were infinitesimal compared with those of a pump having frictional parts; and also that practically no fixing was necessary. Although it had proved a remarkable success, the pulsometer had naturally had to encounter opposition; and perhaps a good deal of odium had been unnecessarily attached to it from the circumstance that when it first came into use it had been the fashion to call it rather facetiously a "steam eater." To a certain extent naturally such a nickname might be applicable, because it would not compare with the higher forms of pumps; but in comparison with the Cornish pumping engine, instead of being 37 times as uneconomical (page 440), it would be seen from the recent test that the pulsometer was only six times less economical; and when the small size and cost of the pulsometer were compared with the vast size and cost of the Cornish pumping engine, this want of economy did not appear to be so serious a drawback to the pulsometer. It was of course largely on account of its extreme convenience that the pulsometer had been so widely adopted, seeing that it required no foundation, and could be handled without trouble, and be put into a well, and even be submerged beneath the water. But more than with any other appliance it was difficult to get the facts of its working, unless from the user himself, because when once it was set to work it did not require attention for months; and the latter was in itself a great practical advantage, in comparison with the working of the duplex or any other direct-acting steam-pump in which there were frictional parts.

Professor T. Hudson Beare said the trial he had made of the pulsometer a few days ago (page 456) had been carried out at the works of the Pulsometer Engineering Co. at Nine Elms, London, according to their ordinary plan of testing their pulsometers before sending them out. The water was lifted by the pulsometer into a tank on a staging about 70 feet above the ground level. The mean height of lift was 73 feet, and by pressure-gauge 84·4 feet including friction. From the elevated tank the water returned by a descending main to the well, and on its way passed through a Kennedy water-meter, which measured therefore the quantity pumped; and for the sake of a positive check the water was measured also in a calibrated tank after leaving the meter. The feed-water was measured with great accuracy by mounting the feed tank on a weighing machine, on

(Professor T. Hudson Beare.)

which the tare weight of the tank itself was balanced; and the weight of feed-water drawn from the tank was noted regularly every ten minutes during the whole trial, which lasted four hours and a half. It might have lasted longer; but the conditions were so absolutely steady during the whole time that it was thought there would be no good in continuing it longer. The observations showed that during the trial the steam consumption was 148 lbs. per water horse-power per hour. Comparing this with the steam consumption given by Mr. Halpin (page 454) of 138 lbs. per water horse-power in the duplex pump, the remarkable result appeared that the pulsometer had practically the same economy, within a difference of only 10 lbs. in 150 or 6⅔ per cent., as the duplex pump, which he supposed must have been of somewhat the same capacity. In order to check the observations made during the trial, they were plotted to a time base, as shown in Figs. 19 and 20, Plate 80, from which it would be seen how uniform the conditions continued throughout the entire duration of the trial; both the rate of pumping and the rate at which steam was used were practically constant. All the observations were taken every ten minutes. Every time the feed-water weight was noted, the level of water in the boiler was also noted; and each point on the feed-water curve in Fig. 19 represented the net feed, that is, after correcting for difference of water-level in the boiler at the time of each observation. At the conclusion the water in the boiler was brought back to exactly the same level as at the start. The trial was entirely under his own control in every respect, and he had the help of four assistants in making it. From start to finish the pulsometer was never touched once, and required not the slightest attention.

In view of this test he thought that, while the results of the trial recorded in the paper must no doubt be quite correct because it had been carried out with great care, yet the deductions from those results might be questioned. The Klestchely trial he conjectured must have been carried out with a pulsometer of old make and probably not in good working order; because it could not be imagined that under any other circumstances would there have been such a huge consumption as 860 lbs. of steam per water horse-power.

Mr. Charles Cochrane, Vice-President, asked what was the precise meaning of the expression " water horse-power."

Professor Beare said it was the horse-power measured in the water actually raised—that is, the pounds weight of water lifted per minute against the feet head, divided by 33,000. In pages 440–1 certain inferences were drawn as to the reasons of the want of economy in the trial of the pulsometer; but he could not admit that the result of that trial was a fair representation of the actual working of the pulsometer under ordinary conditions. The steam consumption seemed surprising, not merely in many of the pumps tried by the author himself, but also in some of the experiments quoted by him from other sources: for instance in the Tangye pump (page 445), where the weight of steam used per horse-power per hour was said to be 855 lbs. He had never dreamt that any machine in use except a rotary engine could eat up steam at such an alarming rate; for even a small non-condensing steam-engine using as much as 50 lbs. weight of steam per horse-power per hour was seventeen times more economical. The pump seemed indeed to be an efficient condenser, and not a proper motor at all.

The President said it looked as if the pistons had been put in without any packing either in the steam cylinder or in the pump.

Professor Alexander B. W. Kennedy, Vice-President, asked whether there might not possibly be some such mistake as the accidental omission of a decimal point in the quoted consumption of 855 lbs. weight of steam per horse-power per hour by the direct-acting steam-pump mentioned in page 445. However that might be, he wished to point out that one highly interesting application of steam-pumps, for other work besides that connected with railways, was their use as feed-pumps; and no doubt it was often a question with others, as it was in his own work, what proportion was borne by the steam used for the feed-pumps only to the steam used in the main engines which the feed-pumps were supplying. If the pumps included in Table 1 (page 437) were considered as feed-pumps, pumping into boilers the

(Professor Alex. B. W. Kennedy.)

water which was to be turned into steam, it seemed that in the first example (trial 18) there were 90 lbs. of water pumped per lb. of steam used by the pump: so that, if an engine were using 90 lbs. of steam, it wanted also 1 lb. to work the feed-pump. And looking down the rest of the figures in the same column it would be seen that, if these particular pumps had been feed-pumps, they would have been using from 1 to 2 per cent. of the whole amount of steam for themselves. These figures of course, as Mr. Lloyd had pointed out (page 451), could not be taken as conclusive, because the pumps were working against all kinds of pressures, and therefore the results could not be directly compared in any way. Having himself often measured the weight of steam used for feed-pumps and compared it with that used by the engines with which they were working, he had come to the conclusion that the amount used for the feed-pump was a most variable quantity, depending even more upon the condition of the pump, and especially of its piston, than upon the kind of pump used. A particular pump might be found to be excessively wasteful, which after being overhauled and repacked might be found to be quite reasonably economical. Especially when pumps were working slowly, as feed-pumps often were, it was quite possible that the mere leakage past the piston might pass as much steam as was actually used by the pump in doing its own proper work; and this waste was apt to become a somewhat serious factor in questions connected with economy. He fully agreed with Mr. Lloyd (page 451) that, while the results given in the paper were highly valuable as representing the actual working of steam pumps, they were difficult to compare, because of the great difference in the size of the pumps. Nevertheless on plotting out, as he had done in Plate 81, the whole of the figures given in the last two columns of Table 4—namely the water horse-power and the work done per pound of steam—it would be seen that curiously enough the several pumps arranged themselves fairly along a regular curve, from the smallest pumps such as the Hayward Tyler at the lower end, to the largest pumps such as the Worthington at the higher: just as if practically the whole of the difference depended upon their size. Although it was obvious that this could not represent the whole o the matter, yet it came out so strikingly as to show plainly how impossible it was to compare small pumps working at only 0·4 or 0·5 horse-power with larger pumps giving from 5 to 15 or 30 horse-power in the work done. The figures reported by Mr. Hodgkin (page 457) from the recent pulsometer trial were most interesting, and had taken himself by surprise, as they doubtless had others also. Probably Mr. Hodgkin indeed had known all about the matter, though hitherto he had been so quiet respecting the performance of the pulsometer; at any rate he was to be heartily congratulated on such a capital result.

Mr. Charles Cochrane thought that, although the weight of 855 lbs. seemed so extraordinary as the steam consumption per horse-power per hour in the direct-acting pump quoted in page 445, yet this particular pump could not well be compared with a pump of any reasonable economy at all, in respect of work done per pound of steam, seeing that it was itself doing no more than only 2,316 foot-pounds per pound weight of steam. Nevertheless the figures themselves here given he thought harmonised with one another, when it was borne in mind that the whole useful work was only 0·148 horse-power; and therefore, while the weight of steam used per horse-power per hour was given as 855 lbs., the 0·148 horse-power represented an actual consumption of only 126 lbs. per hour for the delivery of 797 gallons or 7,970 lbs. per hour; and this agreed with the further statement that the weight of water raised per pound of steam was 63 lbs. The figures quoted in page 445 he therefore thought were correct, apart from any question of economy.

Mr. Leslie S. Robinson suggested the use of hot-air engines for pumping at railway stations. When in Cuba he had desired to find for a large sugar factory a small efficient engine to pump from a well at some distance from the sugar house. Small hot-air engines were being largely used on the railway there; and they certainly had the advantage that there was no boiler to attend to. They were also of simple construction, and did their work satisfactorily; though of course they did not deliver so large an

(Mr. Leslie S. Robinson.)

amount of water as a steam-pump of the same size or weight. It would perhaps be of interest to others besides himself if any information could be given as to whether hot-air engines compared well or badly with steam-pumps in the consumption of fuel.

Mr. G. R. Mather thought that, as the interesting trials described in the paper had been made with pumps of such different ages, some of which had been in use for many years, while others were of modern make, it would be more satisfactory if each of the several makers would have an independent certified test made of one of his most recent pumps. Having himself repaired many kinds of pumps, he had found that after repair their economy of work had sometimes been doubled. Therefore the results given in the paper, although they might be of some use as showing what was the actual state of things existing on the railways referred to, could not be of any great use for drawing comparisons between the different kinds of pumps. As to their comparison with the Cornish pumping engine, it must be borne in mind that the high economy of the latter was chiefly owing to the great momentum of its working parts, which was wanting in the steam pumps dealt with in the paper; even in those which were of the most modern make and had been compounded, the momentum of the working parts was not sufficient to be made use of for enhancing their economy.

Mr. E. H. G. Brewster gathered from the descriptions given in the paper that many of the pumps were old; and as they had all been tried without being put into thorough order, the trials seemed to him to be of no value, and the report of them to be not just to the makers of the pumps.

Mr. Edward B. Marten, Vice-President, had gladly hailed the offer of this paper to the Institution, because it gave the actual facts from a user, who stated what he had found his pumps were doing in ordinary working. The figures contained in the tables the author had tried to give in the most convenient form; and afterwards had commented upon them, in order to show how lamentably the useful effect was less than what it ought to be in comparison with other forms of pumping engines. The main object of the paper, and the object equally of the Institution, certainly was to elicit the same kind of experience from any one who had it; and he was glad that his own opinion of the scarcity of such information as that contained in the paper was confirmed by two of the speakers, who said that they had searched elsewhere and could not find such a good set of examples of steam pumps in everyday use. The Institution therefore he thought would profit much by the paper; and it would be an advantage if future statements of the duties of pumps were put in the same convenient form which had been adopted in the paper, showing the work done in foot-pounds of water lifted per pound of steam. Having himself searched diligently for any such particulars, he had found some supplied by Professor Unwin (Society of Arts Journal, 8 Sep. 1893, page 896), which were reproduced in the first four columns of Table 6. Taking the assumption made in the paper (page 440), that one pound of coal, burnt under favourable conditions of boiler firing, would evaporate ten pounds of water, he had added the fifth column in order that the duty reported in the paper might be compared with that here recorded from seven small engines of various kinds working in Birmingham. The trials included in Table 6 he understood had

TABLE 6.

Duty of seven Small Engines in Birmingham.

Nominal Power.	Probable Power at full load.	Average Power observed.	Coal Consumption observed per I.H.P. per hour.	Work Done per pound of Steam.
H.P.	I.H.P.	I.H.P.	Lbs.	Ft.-Lbs.
4	12	2·96	36·00	5,500
15	45	7·37	21·25	9,317
20	60	8·20	22·61	8,757
15	45	8·60	18·13	10,920
25	75	23·64	11·68	16,952
20	60	19·08	9·53	20,776
20	60	20·00	8·50	23,294

(Mr. Edward B. Marten.)

been made for the purpose of showing that by combined pumping for a general distribution of hydraulic power, although there would be a certain amount of loss, yet the economy of producing the power in that way would be far greater than was shown in these examples, in which the engines had been tested in the workshops of the users. It would be seen that three of the engines were working at only one-third of their probable full load, and the other four at still less, which would largely account for the poor duty shown. The figures he had added in the fifth column merely enabled some sort of comparison to be made with other performances recorded in the same way, namely in work done per pound of steam.

Three other examples were given in Table 7, showing in the first five columns the results obtained by Professor Unwin in a trial of small semiportable engines at the Plymouth show of the Royal Agricultural Society (Journal 1890, pages 587–9). To these also he had here added a sixth column to show the foot-pounds per pound of steam at the actual rate of evaporation; and a seventh column for comparison with the duty reported by Mr. Borodin, assuming an evaporation of ten pounds of water per pound of coal, although this was seldom reached in such small boilers. To make the figures compare absolutely, they should of course be the foot-pounds of

TABLE 7.

Duty of three small Semiportable Engines.

Maker.	Indicated Horse-power.	Welsh Steam Coal consumed per I.H.P. per hour.	Water evaporated per pound of Coal.	Steam consumed per I.H.P. per hour.	Work Done per pound of Steam,	
					at actual rate of evaporation.	at rate of 10 lbs. steam per lb. coal.
*	I.H.P.	Lbs.	Lbs.	Lbs.	Ft.-Lbs.	Ft.-Lbs.
S	5·641	4·099	8·726	35·75	55,385	48,304
T	5·175	8·461	7·65	64·73	30,588	23,401
A	6·201	9·66	5·978	57·75	34,286	20,497

* S = Simpson, Strickland and Co., Dartmouth; compound.
T = E. R. and F. Turner, Ipswich; single cylinder.
A = Adams and Co., Northampton; single cylinder.

actual work, not including the engine—that is, per water horse-power instead of per indicated horse-power; but for the present purpose the figures here given were sufficient.

It so happened that he was himself using a good many small pumps: in one instance to the extent of lifting when required about seven million gallons a day. All kinds of pumps were used, including the injector, the pulsometer, and centrifugal; and he quite agreed with the author in not wishing to disparage any of them for certain uses. For many purposes of his own he found nothing was more convenient than the pulsometer, of which he was often glad to make use because it was so handy. He had therefore been rather staggered at the poor duty attributed to it in the paper, and was glad the maker's recent trial had shown that it could usually do better; the duty of one which he was himself using he had somewhat roughly calculated at about 4,300 ft.-lbs. per pound of steam. Even the injector, which was so wasteful, had been found under certain circumstances to be a most convenient instrument: it occupied so little space that a man could creep into a culvert into which he could only just crawl, take it with him, and keep himself from drowning. There were few pumps of which this could be said; and therefore even the injector, although it seemed so bad, was still found to be extremely useful. A great deal of the bad duty of pumps was owing to the fact that a bigger pump was ordered than was really wanted, or a pump was provided which would meet the greatest emergency; and at all times excepting just those of emergency it was almost certain that such pumps would do bad duty. These various pumps he had himself had to use on emergency, when of course it did not matter how much steam they took; but any that were meant for emergency were not good for ordinary work. None the less did he feel much indebted to the author for bringing the matter forwards so clearly and in such an easy way; everyone could turn the amount of work done by a pump into the work done per pound of steam, whereby a comparison could easily be made with the results given in the paper; and since reading these he had himself been turning into this form the duty of any engine pumping water. In this way he had found that the

(Mr. Edward B. Marten.)

duty of one of the Tangye direct-acting pumps which he was using came out at about 9,000 ft.-lbs. per lb. of steam, instead of the much lower duty quoted in page 445 of the paper; it was lifting 280 gallons of water 12 feet high per minute, and was thus working at a little over one horse-power, instead of only the 0·148 horse-power in page 445. Why however the pumps tried by the author should be so uneconomical still puzzled him. From their small size he could understand their being uneconomical to a certain extent; but the question arose whether they unnecessarily reversed the direction of flow of the water current, and so wasted a great deal of power inside the pumps themselves. Or why else was it that, after all, the best of them, as pointed out by the author (page 440), were not much to boast of? This he thought was a matter for engineers to consider with regard to pumping water, and to see whether they were going to be content with such a poor duty. With much larger pumps a good duty was obtained; and surely with smaller pumps some means should be contrived of doing work on a small scale with an economy more nearly approaching that of the larger pumps.

Mr. Edward Furness thought one of the principal reasons for the variations in the results shown in the paper might be the difference in the speed at which the pumps were driven. A pump which he had tested required proportionately a great deal more power to drive it at 100 revolutions per minute than at its proper speed of about 60 or 70; and at the higher speed the shocks from the change of direction in the current through the pump were so considerable as to take up a great deal of power. It was owing he thought to the much more frequent change of direction of the water in the small pumps that they took up so much more power than the large Cornish pumping engines.

Mr. W. G. Walker had made a number of experiments himself with steam pumps, but had not known where to find any information on the subject. One point which had certainly been brought out by the author's figures was that the efficiency of small engines or small pumps was low compared with that of larger engines or larger pumps, which developed greater power.

Mr. John Phillips noticed that in Table 4 the speed of the pumps was given in double strokes or revolutions per minute; and he thought it would be an advantage if the diameters were given of the steam cylinder and pump, with the length of stroke; as also, in the case of the geared pumps, the revolutions of the engine and the corresponding strokes made by the pump; and the sizes of the pulsometers and injectors. With regard to the condition of the several pumps at the time of their being tried, he thought there could not be a fair comparison unless they were in good order. The results given were from pumps which had been in use for various periods; some would doubtless be in better condition than others. It might also be expected that, owing to their different systems, some would keep in repair longer than others: for instance, the larger slow-moving pump driven by gearing, as compared with the ordinary self-contained steam-pump or donkey-pump making a greater number of reciprocations.

The President presumed the author had wished to try the pumps just in the actual condition of their ordinary working at the time.

Mr. George Cawley feared the comparison between the pumps described in the paper and the old Cornish pumping engine would not bring much comfort to the modern pump-makers, if the most economical of the steam pumps tried (page 440) was about 2½ times less efficient than the Cornish engine. Yet even then justice was scarcely done to the Cornish engine; for if he remembered right, instead of the maximum mentioned of 112 million foot-pounds of work per cwt. of coal, the duty in one instance had been even as much as something like 120 millions. Taking however the 112 millions as a convenient figure because 112 lbs. made 1 cwt., the duty of the old Cornish pumping engine would be exactly one million foot-pounds of work per pound of coal, corresponding nearly with

(Mr. George Cawley.)

2 lbs. of coal per hour per water horse-power or per brake horse-power, which was really an astonishing result, placing the Cornish engine of fifty or sixty years ago far beyond any other practical machine for converting heat into mechanical energy; in fact, having regard to the low steam-pressures then employed, he did not quite understand how that astonishing economy had been got. Apart from the boiler indeed, the Cornish engine itself was even a little better than was represented by the author, who made the engine duty equivalent to 100,000 foot-pounds of work per pound of steam on the assumption that 10 lbs. of water were evaporated per pound of coal. The old Cornish boiler however at that time he thought would not evaporate more than 8 lbs. of water or even less per pound of coal; but taking 8 lbs., this would give a duty of 125,000 foot-pounds of work per pound of steam in the Cornish engine, representing more than three times the efficiency of the best steam-pump in the author's trials.

The President moved a hearty vote of thanks to Mr. Borodin for the interesting and valuable information which he had given in his paper.

Mr. Thomas Urquhart, late locomotive superintendent of the Grazi and Tsaritsin Railway for many years, wrote that he was prevented by ill health from attending the meeting, and he sent the following Table 8 (pages 472–3) and diagram, Plate 82, showing the cost of water supply on that line per thousand axle-miles of trucks and carriages during the nine years 1882-1890. The total cost is here made up of the six items following:—A wages of engine-men and stokers; B fuel for steam boilers; C fuel for warming water-columns and tanks in winter; D fuel for engine-men's quarters; E lighting rooms, cleaning and lubricating machinery; F repairs of engines, pumps, and boilers. The proportions of these several items are seen from the diagram at a glance. The total cost declined from 13·404*d.* in 1882 when burning coal alone, to 7·044*d.* in 1890 when burning petroleum refuse alone. Coal alone was used in the three years 1882-3-4; then partly coal and partly petroleum refuse in the next two years 1885-6; and afterwards petroleum refuse alone in the last four years 1887-90. The most expensive year was 1884, when the coal burnt was all new, without any riddlings from the ashpits of the locomotives then fired with coal. Afterwards there is seen to be a continuous and decided decrease in the cost of firing B, consequent upon the introduction of petroleum refuse as fuel for the boilers of all the water-pumping engines.

In Table 9 (page 474) and diagram, Plate 83, is shown a comparison for 1890 with similar costs on three other lines, having profiles of a character similar to that of the Grazi and Tsaritsin Railway. This comparison shows the total cost of water supply per thousand axle-miles of trucks and carriages to have been as follows:—

Grazi and Tsaritsin	7·044	pence
Orel and Witebsk	7·452	,,
Moscow and Brest	7·380	,,
Kosloff, Voronesh, and Rostoff . .	11·728	,,

On the last railway the water undergoes also chemical purification, which is accountable for one penny of the total cost, as shown at G in the diagram.

Unlike Great Britain, on the Russian railways almost without exception it is necessary to pump water up to the station tanks by steam power, in consequence of natural gravitation supplies being so few in such an exceedingly flat country.

(Mr. Thomas Urquhart.)

TABLE 8 (*continued on opposite page*).

Cost of Water Supply on the Grazi and Tsaritsin Railway during nine years 1882–90.

See Plate 82.

Items of Cost.	1882.	1883.	1884.
Per thousand axle-miles of trucks and carriages.	Pence.	Pence.	Pence.
A Wages of engine-men and stokers	4·428	3·960	3·612
B Fuel for steam boilers . . .	5·856	6·192	6·696
C Fuel for warming water-columns and tanks in winter . .	0·384	0·288	0·480
D Fuel for engine-men's quarters .	0·528	0·468	0·420
E Lighting rooms, cleaning and lubricating machinery .	0·420	0·336	0·336
F Repairs of engines, pumps, and boilers	1·788	1·632	2·388
Total Cost of Water Supply per thousand axle-miles of trucks and carriages . .	13·404	12·876	13·932
	Miles.	Miles.	Miles.
Total Axle-Miles of trucks and carriages . . .	97,927,740	113,579,960	124,461,939
Engine Miles . . Profitable	1,768,804	1,952,037	2,058,742
Engine Miles . . Total . .	2,534,638	2,621,180	2,773,157
	£ *s.* *d.*	£ *s.* *d.*	£ *s.* *d.*
Cost of Water Supply per thousand engine-miles Profitable	3 1 10	3 2 5	3 14 0
Cost of Water Supply per thousand engine-miles Total . .	2 3 1	2 6 5	2 12 9
Mean yearly cost of working of one Water Station . . .	160 17 9	179 8 11	212 10 6
Total yearly cost of working of all Water Stations . . .	5,470 2 7	6,094 8 7	7,225 16 6
Fuel used	Coal alone.		

(*concluded from opposite page*) TABLE 8.

Cost of Water Supply

on the Grazi and Tsaritsin Railway during nine years 1882–90.

See Plate 82.

1885.	1886.	1887.	1888.	1889.	1890.
Pence.	Pence.	Pence.	Pence.	Pence.	Pence.
3·780	3·996	3·480	3·492	3·156	3·144
5·328	4·824	3·360	3·324	2·808	2·532
0·204	0·288	0·204	0·168	0·384	0·336
0·396	0·408	0·384	0·336	0·324	0·336
0·288	0·144	0·108	0·096	0·084	0·084
1·764	1·320	1·884	1·176	1·260	0·612
11·760	10·980	9·420	8·592	8·016	7·044
Miles.	Miles.	Miles.	Miles.	Miles.	Miles.
126,569,995	118,900,533	136,420,000	136,909,500	148,765,178	149,286,657
2,020,192	1,856,285	2,041,467	2,105,891	2,259,030	2,181,139
2,800,606	2,754,884	2,762,238	2,924,589	3,161,144	3,027,305
£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
3 1 4	2 18 6	2 13 2	2 9 2	2 4 0	2 0 3
2 4 3	1 19 6	1 18 8	1 13 4	1 11 5	1 8 11
182 7 11	160 1 1	157 6 11	143 11 2	150 13 11	133 0 11
6,201 10 11	5,441 17 10	5,349 16 3	4,880 19 9	4,973 0 11	4,390 9 7
Coal and Petroleum Refuse.		Petroleum Refuse alone.			

(Mr. Thomas Urquhart.)

TABLE 9.

Comparative Cost of Water Supply per thousand axle-miles of trucks and carriages on four Russian Railways in 1890.

See Plate 83.

Items of Cost.	Grazi and Tsaritsin.	Orel and Witebsk.	Moscow and Brest.	Kosloff Voronesh and Rostoff.
Per thousand Axle-miles of trucks and carriages.	Pence.	Pence.	Pence.	Pence.
A Wages of engine-men and stokers .	3·144	3·348	2·520	4·212
B Fuel for steam boilers . . .	2·532	2·770	2·900	3·204
C Fuel for warming water-columns and tanks in winter . . .	0·336	0·224	0·296	0·470
D Fuel for engine-men's quarters .	0·336	0·210	0·260	0·466
E Lighting rooms, cleaning and lubricating machinery . .	0·084	0·180	0·468	0·180
F Repairs of engines, pumps, and boilers	0·612	0·720	0·936	2·196
G Chemical purification of water .	Not adopted on these three lines			1·000
Total Cost of Water Supply in 1890	7·044	7·452	7·380	11·728

Mr. John Barr, being unable to attend the meeting, wrote that of the pumps described in pages 434–5, so far as would appear from the description, only the Reschitz pumps, pulsometers, and injectors seem to be adapted to pump from wells. With regard to the new pumps now being put up on the South Western Railways (page 436), which are mentioned as being exclusively of the Worthington or Blake kind, are these pumps then made with bell-cranks? or are they placed vertically over a well? or are there no wells with water lower than about 24 feet below the surface of the ground?

With respect to the proportion of indicated horse-power to pump horse-power, referred to in page 439, in 1887 the writer made some experiments with a vertical engine of 6 horse-power nominal, driving deep-well pumps by gearing, as used by the Indian State Railways; the indicated horse-power was 7·8 and pump horse-power 4·6, or a ratio of 1·0 to 0·6; that is, the efficiency was 60 per cent. In January 1893 a similar engine doing more work was tested; the average of four experiments gave indicated horse-power 9·8, pump horse-power 7·6, or an efficiency of 77 per cent. In 1891 some experiments were made with a small horizontal steam-engine of 4 horse-power nominal, to determine the indicated and brake horse-power; the average results showed that the efficiency was 77 per cent.

In the writer's view the Cockerill pumps do not get the credit they deserve. In Table 3 (page 443) the work done by the old Cockerill pump is given as 24,940 ft.-lbs. per lb. of steam, while that of the new Worthington compound at the same station is 32,810 ft.-lbs. Referring to Table 4 (page 447), the useful effect of the same Cockerill pump was 80 per cent., while that of the same Worthington compound was 97 per cent. If therefore the pump valves of the old Cockerill pump had been put into good order, it would seem that it would have shown a better result than the new Worthington pump.

Regarding slip of pumps, that found with the Indian State Railways pump when new was 3·65 per cent.; that is, the useful effect of the pump was 96·35 per cent.

Mr. Edward B. Marten, Vice-President, wrote that he was informed by Messrs. John and Henry Gwynne that their "Invincible" pumping engine at Groote Ypolder in Holland, with centrifugal pump 39 inches diameter, gave out 67,000 ft.-lbs. of work done per lb. of steam, in an independent trial made on 23 October 1891; the height of lift was only $13\frac{1}{4}$ feet, and they did not know any other water-raising machine that had given out anything like this duty on the same low lift. In Mr. Borodin's trials the best result obtained was with the Worthington pump, compound condensing, namely 39,700 ft.-lbs. per lb. of steam (trial 30, page 449), and this was on a lift equal to 591 feet. On such a high lift they did not consider this performance anything particularly good for a piston pump, as it was on high lifts that the good points of a force pump came out.

Mr. Druitt Halpin wrote that he had made a test during one hour with a pulsometer of the size known as No. 11, which was described as capable of discharging 65,000 gallons per hour, having a 10-inch suction pipe, an 8-inch delivery, and a 2-inch steam pipe. The mean number of pulsations per minute was 41, and the discharge was 70,078 gallons in the hour's trial. The mean steam pressure was 42 lbs. per square inch above atmosphere, and the mean height of lift $16\frac{1}{4}$ feet. The temperature of the water to be lifted was 50° Fahr., and on its discharge 53°, which however was read only on an ordinary thermometer; the observations were made as closely as possible, but of course cannot be credited with the accuracy which could have been obtained with a thermometer having a more open scale, specially adapted for reading small differences of temperature. The total quantity of steam used was 1,763 lbs.; the work done was therefore $700{,}780 \text{ lbs.} \times 16\frac{1}{4} \text{ ft.} \div 1{,}763 = 6{,}459$ ft.-lbs. per pound of steam. The horse-power in the work actually done was $700{,}780 \text{ lbs.} \times 16\frac{1}{4} \text{ ft.} \div (33{,}000 \times 60) = 5\cdot75$ horse-power; and the steam consumption was therefore $1{,}763 \div 5\cdot75 = 306\cdot6$ lbs. per water horse-power per hour. For a heat balance, the 1,763 lbs. of steam leaving the boiler at 57 lbs. total pressure would contain $1{,}763 \times 1{,}201^\circ = 2{,}117{,}363$ heat-units. The increase of temperature in the discharged water would account for 700,780 × 3° = 2,102,340 heat-units or 99·29 per cent., and the work done for 700,780 × $16\frac{1}{4} \div 772$ = 14,750 heat-units or 0·697 per cent., leaving only 273 heat-units or 0·013 per cent. for the loss by radiation. As this percentage of loss is evidently too low, it is clear that the correct amount of the rise in temperature of the discharged water must have been less than was observed with the thermometer.

An official test he noticed ("Engineering," 24 Nov. 1893, page 639) had been made in Hanover on 9 June 1892 of a Körting pulsator, having 11·27 feet height of suction and 102·6 feet total height of delivery through a delivery pipe of 118 feet horizontal length, with the result that 24,188 gallons of water per hour were delivered, and the steam consumption was 92·76 lbs. per pump horse-power per hour; the work done per pound of steam was therefore 21,345 foot-pounds.

Mr. Borodin wrote that, agreeably with the wish expressed in the discussion (pages 454 and 469), general diagrams of the several kinds of pumps tried were given in Plates 72 to 78; and Table 5 was added (page 450), giving the diameter and length of stroke of the steam cylinders and pumps.

The Worthington and Blake pumps used on the Russian South Western Railways (page 475) are exclusively of the horizontal kind, as shown in Plates 76 to 78. Where the level of the water is lower than 20 feet below the surface of the ground, the pump is lowered in a dry well in the pump house to the required depth.

In reference to the suggestion (page 461) whether there might not possibly be some such mistake as the accidental omission of a decimal point in the quoted consumption of 855 lbs. weight of steam per horse-power per hour by the direct-acting steam-pump mentioned in page 445, a mistake of that kind, but in the opposite direction, was actually made in regard to this very figure in the results quoted in a table in the Proceedings of the Mulhouse Society, where the weight of steam used per horse-power per hour was given as 38·269 kilogrammes, instead of the correct consumption of ten times as

(Mr. Borodin.)

much; and the same mistake occurred in the rest of the figures given for the steam consumption per horse-power per hour in the table referred to. In page 445 the consumption of 855 lbs. is correct, being 7,970 lbs. ÷ (63 × 0·148); and, as rightly pointed out by Mr. Cochrane (page 463), the figures here quoted harmonise with one another. The huge consumption per water horse-power does not seem so surprising for a pump yielding no more than 0·148 horse-power in useful work, which is quite disproportionate to the large size of the pump, the steam cylinder being 4 inches and the pump 2 inches diameter, for lifting water through the height of only 36·7 feet. For such a low useful work the employment of a pulsometer might certainly be recommended, as it has no internal friction; whereas in pumps lifting only a small height the friction of the pump itself is probably many times greater than the useful work.

The author quite agrees with Mr. Marten's remark (page 467) that a great deal of the bad duty of pumps is owing to the fact that a bigger pump was ordered than was really wanted. This was the case with many of the pumps included in the paper, where the steam cylinder might have been made of a smaller diameter. In Table 6 (page 465) it will be seen that the estimated work done per pound of steam by pumps of corresponding horse-power is much less than in the trials recorded in Table 4, as shown by the following comparison:—

From Table 4, pages 446–9.			*From Table 6, page* 465.	
Number of Trial.	Water Horse-power. W. H. P.	Work done per pound of Steam. Ft.-Lbs.	Indicated Horse-power. I. H. P.	Work done per pound of Steam. Ft.-Lbs.
3	2·47	10,760		
4	1·38	9,840		
5	1·97	7,190	2·96	5,500
25	2·12	16,830		
26	1·78	11,250		
13	8·19	24,940		
14	5·21	18,050	7·37	9,317
34	7·89	23,590	8·20	8,757
35	5·76	22,080	8·60	10,920
36	5·13	21,460		

In the light of this comparison the author does not understand why the uneconomical results recorded in the paper should seem puzzling. The duty of 9,000 ft.-lbs. per lb. of steam, mentioned as having been obtained from Mr. Marten's Tangye pump (page 468), cannot by itself be contrasted with M. Meunier's result, because the horse-power of the useful work is much greater in the former, namely one horse-power, instead of only the 0·148 horse-power given in page 445.

On the high duty of 13,415 foot-pounds per pound of steam, attained by the pulsometer (page 457), Mr. Hodgkin must be congratulated; and if such a duty could be guaranteed, then certainly all small pumps would have to be replaced by pulsometers. Unfortunately the duty of the one used by Mr. Marten (page 467) was only 4,300 ft.-lbs., which is much nearer to the author's result of 2,300 ft.-lbs. in trial 15 (page 447) than to the high duty in Professor Beare's trial. In view of such discrepancies the author thinks it would be useful to make comparative and reliable tests, duly checked, with several kinds of small pumps and with pulsometers, in a testing shop properly fitted up. By such tests much light might be thrown upon the best kind of pump for a given work; and a real advance in the construction of pumps would be the result.

EXPERIMENTS ON HEAT LOSSES FROM DRY AND WET CYLINDER WALLS EXPOSED TO A VACUUM &c.

By Mr. BRYAN DONKIN, of London.

The experiments here described were arranged by the author in 1891 with the view of obtaining some information as to the cooling effects produced upon the internal surfaces and upon the metal of engine cylinders during the exhaust period of the stroke, when exposed to a condenser. They were made by injecting small quantities of warm water into the interior of a cast-iron cylinder, in which a vacuum was maintained. It was particularly desired to ascertain the distance to which the cooling effect of these injections extended into the metal, and the resulting reduction in the temperature of the cast-iron walls. The weight of the metal being known, and also its mean temperature both before and after the injections, the quantity of heat lost in a certain time under given conditions could be ascertained in thermal units per minute.

Arrangements were made for raising the temperature of the cylinder by means of a number of small gas jets placed externally. When the required temperature was obtained, the gas was turned off, and the hot metal exposed internally to the condenser, either with or without injections of water. Experiments were also made, by keeping the cylinder hot and giving a single injection of water, to determine the thermal effects thereby produced throughout the thickness of the metal exposed to the vacuum. The temperature of the metal was taken by means of thermometers inserted in small holes drilled longitudinally in the cylinder walls. The injection of water affected these thermometers through a considerable thickness of metal: the range thus shown in temperature of the metal becoming less as the distance from the internal surface of the cylinder was greater.

It was also desired to determine the loss of heat, if any, from the dry cylinder walls exposed to the vacuum. Various experiments proved that there was practically none under the conditions of these tests.

Description of Apparatus.—The apparatus illustrated in Figs. 1 and 2, Plate 84, was fixed in the engine-house at Messrs. Bryan Donkin and Co.'s works at Bermondsey, and connected by a short pipe to the condenser of a beam engine. It consisted of a small vertical cast-iron cylinder with walls 1 inch thick, 2 inches internal and 4 inches external diameter, and 3 inches long, closed at both ends. The internal wall area was 24·35 square inches, or 0·169 square foot. To the bottom cover was attached a pipe leading to the condenser; and when the cock on this pipe was open, the interior of the cylinder was in direct communication with the condenser. The water was admitted into the cylinder from a glass vessel situated above it, by a pipe projecting through the top cover as shown. The water entered horizontally through three small holes in this pipe, so that it played against the vertical walls and wetted them in the form of fine spray, their inner surface being thus exposed wet to the vacuum. Owing to the difference of pressure between the atmosphere and the condenser, the water entered the cylinder with great rapidity. From one to ten injections per minute could be made by means of the top cock, and the quantity entering the cylinder could be varied from 0·03 to 0·12 cubic inch per injection.

By means of the small gas jets placed round the outside of the cylinder as shown in Fig. 2, it could easily be heated up to a temperature of 300° Fahr. or more. The walls could be kept at this temperature if desired; or after they had been heated up to 300°, the gas could be turned off in order to determine the quantity of heat lost under different conditions. This method of heating the walls worked easily and gave no trouble; the temperature required was readily obtained. The temperatures throughout the metal walls were ascertained in a similar manner to that described and illustrated in Proceedings Inst. Civil Engineers, vol. c, 1890, page 347. As shown in Figs. 3 and 4, Plate 84, eight vertical holes, 0·16 inch diameter, were drilled into the metal walls and filled with mercury; small thermometers placed in these holes gave the various temperatures of the metal. The distances of the sides of these eight holes from the inner surface of the cylinder, that is the thicknesses of the intervening metal, were respectively

	B	C	D	E	F	G			
mm.	1½	3	6	9	12	15	18	21	mm.
inch	0·06,	0·12,	0·24,	0·35,	0·47,	0·59,	0·71,	0·83	inch.

Another thermometer was placed in a thin steel cup about 3 inches deep with walls 1–6th millimetre = 0·0065 inch thick, which was filled with mercury and screwed into the top cover so as to project into the interior of the cylinder. The readings of this thermometer were also recorded in the third series of experiments.

Nature of Experiments.—Three series of experiments were carried out with this apparatus. In the first and second it was desired to determine quantities of heat lost from the cylinder. The walls were first heated up to about 300° Fahr., and the gas was then turned off at the commencement of each experiment; thus a given weight of metal was at that temperature at starting, and was found to be reduced to a lower temperature at the end of the experiment. In the accompanying Table 1, pages 484–5, experiment No. 1 of the first series was made to determine the quantity of heat lost by external radiation; it was therefore made with dry hot walls, without water injection. The second series were made to determine the quantity of heat passing from the wet hot walls to the condenser, a certain number of water injections being admitted per minute. The third series were made to determine the cooling effect produced by a single injection of water upon the cylinder walls when these were kept during the experiment at a temperature of about 300° by the gas jets, so as to obtain about the same temperature as that given by hot steam-jackets of ordinary engines; in this way it was desired to obtain the data for plotting, on a time basis, the curve of the cooling wave through the different thicknesses of metal, as shown by the various thermometers.

First Series. Cooling of Dry Hot Walls.—The conditions and results of experiment No. 1 are given in Table 1; other experiments confirmed this. The cylinder wall was heated by means of the gas jets until the mean reading of the eight thermometers was 300° Fahr., when the gas was turned off; and no injection water was admitted into the cylinder. After the first half-hour, the mean temperature of the metal had fallen to 163°; after the second half-hour to 114°; after the third to 93°; and after the fourth to 82°: the fall in the same time being less as the difference in temperature between the metal and the surrounding air became less. These temperatures plotted to a time base form a regular curve. If the fall in temperature during $\frac{1}{2}$, 1, $1\frac{1}{2}$, and 2 hours from the commencement of the experiment be multiplied by 2·16 lbs., which is the product of the weight of the metal multiplied by its mean specific heat, the total loss of heat from the metal during each of these periods is obtained; it is given in Table 1. The fall of temperature was due to external radiation only, as it was found that there was no additional loss of heat when the internal surface of the walls was exposed to the condenser. The same experiment was repeated several times with the vacuum cock both open and shut, and always with the same thermal result: so that the figures given in experiment No. 1 represent the loss externally, or by radiation only into the engine-room, whether the internal surface of the walls was exposed to the condenser or not. It may therefore be concluded that with dry walls varying in temperature from 300° to 82°, no heat passed from the cylinder to the condenser, the temperature in the latter being about 120°. This was no doubt due to the absence of any medium for conveying the heat, the condenser temperature being generally much lower than that of the walls. These experiments agree with the results of several other tests made by the author by different methods on an experimental steam-engine in which the temperature of the walls was also taken.

Second Series. Cooling of Wet Hot Walls exposed to a Vacuum.—In this series the conditions and results of thirteen experiments, Nos. 2 to 14, are given in Table 1, pages 484–5. Nos. 2 to 5 lasted for

TABLE 1 (*continued on opposite page*).

Experiments on Heat Losses from a Cast-Iron Cylinder with Dry and Wet Walls.

No. of Experiment. 1891.	Duration of Experiment.	Mean Temperature of Walls, measured in eight holes.			Temperature of Engine House.
		At beginning of experiment.	At end of experiment.	Total Fall during experiment.	
No.	Minutes.	Fahr.	Fahr.	Fahr.	Fahr.
Series 1. *Cooling of Dry Hot Walls, exposed to a Vacuum or not.*					
1	30	300°	163°	137°	76°
	60	300°	114°	186°	76°
	90	300°	93°	207°	76°
	120	300°	82°	218°	76°
Series 2. *Cooling of Wet Hot Walls, exposed to a Vacuum.*					
2	30	319°	88°	231°	75°
3	30				
4	30	312°	100°	212°	79°
5	30				
6	60	312°	87°	225°	79°
7	60				
8	60	316°	98°	218°	78°
9	60				
10	60	292°	96°	196°	76°
11	60	312°	94°	218°	77°
12	60				
13	60	296°	96°	200°	77°
14	60				

(*concluded from opposite page*) TABLE 1.

Experiments on Heat Losses from a Cast-Iron Cylinder with Dry and Wet Walls.

Vacuum in Cylinder. Inches of mercury.	Amount of Water injected into Cylinder.			Total Loss of Heat from Cylinder Walls during experiment.	No. of Experiment. 1891.
	Quantity per Injection.	No. of Injections per minute.	Weight per minute.		
Inches.	Cub. inch.	No.	Lb.	Th. U.	No.
Series 1. *Cooling of Dry Hot Walls, exposed to a Vacuum or not.*					
25·50	..	..	..	296	1
25·50	..	..	..	402	
25·50	..	..	..	447	
25·50	..	..	..	471	
Series 2. *Cooling of Wet Hot Walls, exposed to a Vacuum.*					
26·00	0·12	10	0·0440	499	2 3
26·25	0·12	5	0·0220	458	4 5
26·25	0·12	1	0·0044	486	6 7
26·50	0·06	1	0·0022	471	8 9
27·00	0·06	1	0·0022	423	10
26·50	0·03	2	0·0022	471	11 12
26·50	0·03	1	0·0011	432	13 14

half an hour, and Nos. 6 to 14 for an hour. The cylinder having been raised to between 292° and 319° Fahr. at the beginning of each experiment, the gas was then turned off, and a quantity of water varying from 0·03 to 1·20 cubic inch per minute was injected at a temperature of 150°. A little air unavoidably entered with the water, and to a certain extent contributed to the loss of heat. Comparing experiment No. 1 for half an hour with Nos. 2 and 3 for the same time, it will be seen that, with 0·12 cubic inch of water injected ten times per minute, the loss of heat was considerably increased when the wet walls were exposed to the condenser. With half the above quantity of water injected, Nos. 4 and 5, the loss of heat was nearly as great: which seems to indicate that in the previous experiment the whole of the water injected was not evaporated from the walls. The loss of heat from the cylinder did not vary, whether 0·06 cubic inch was injected every minute, as in Nos. 8 and 9, or 0·03 cubic inch twice a minute, as in Nos. 11 and 12. In experiment No. 10, in which also 0·06 cubic inch was injected every minute, the water cock was opened and shut more rapidly, so as to admit as little air as possible; and this may account for the rather smaller loss of heat as compared with Nos. 8, 9, 11, and 12. The smaller quantities of water were evidently evaporated rapidly at the low condenser-pressures, thus carrying away the heat from the hot walls. In making comparisons between experiments 2–14 and experiment 1, care should be taken to consider not only the question of time, but also that of the temperature range of the metal. The temperature of the surrounding air was practically the same in these tests. This loss of heat from wet hot walls has an important bearing on what takes place on the internal surfaces of low-pressure cylinders of condensing steam-engines, where much water is often present; and confirms the opinion of many eminent authorities.

Third Series. Cooling effects produced through different thicknesses of the metal wall by a single Injection.—In this series the outside of the same cylinder was maintained at a temperature of from 290° to 310° Fahr. by means of the external gas jets, while the internal surface was exposed to a vacuum of 26½ inches of mercury, corresponding with a temperature of 121°. A single injection of 0·03 cubic inch of water at a temperature of about 200° was made in each experiment, and the effects on the different thermometers were noted every few seconds.

The results are shown graphically in Figs. 5, 6, and 7, Plates 85 and 86. Fig. 5 shows the range of temperature of the metal through about 5–8ths of its thickness of 1 inch, produced by the injection of 0·03 cubic inch of water, as shown by the thermometers in the six innermost holes. The upper line is drawn through all the maximum temperatures, and the lower line through all the minimum; the vertical distance between these two curves represents therefore the range of metal temperature within the iron itself, at the different distances at which the thermometers were placed from the inner surface. The fall from the higher to the lower temperature was very rapid, as seen from Figs. 6 and 7. It will be observed from Fig. 5 that, as the distance from the cooled internal surface increases, the range of temperature of the metal decreases. Figs. 6 and 7 show the thermal speed, or the time taken to pass through the cast-iron according to the distance from the inner surface of the metal. Here the conditions were a hot and wetted internal cylinder wall exposed to the vacuum. The thermometers placed in the different holes showed the changes in the temperature of the metal throughout its thickness. Thus in the first hole B, nearest to the inner surface of the cylinder, the temperature fell from 295° to 284° Fahr. or 11° in five seconds; in the sixth hole G it fell only 1° in nine seconds. Fig. 6 shows the rates at which the temperature fell in the steel cup, and in the six holes nearest to the inner surface of the cylinder wall; and also the curves of recovery of temperature after the injection, by conduction from the hotter portions of the metal, the recovery being much more gradual than the fall of temperature after the injection. In the two holes nearest the outside of the cylinder the temperature was practically unaffected by the injection. Fig. 7, Plate 86, shows the rates at which the temperature fell in the steel cup and in the first and second holes, in another experiment in which the observations were taken much more frequently.

Speed of Thermal Propagation through the cylinder wall.—From the observations in the third series of experiments, plotted in Fig. 6, the mean rate of propagation of the cooling effect through the metal has been worked out; and the results are given in Table 2. In this table column 1 gives the letters of the thermometer holes, commencing at the inner surface of the cylinder; column 2 gives the distance from the inner surface of the cylinder to each hole, that is the thickness of metal through which the cooling effect had to travel; column 3 gives the fall of temperature due to the injection; column 4 gives the time after the injection that each thermometer took to reach its lowest temperature, that is the time the cooling effect took to travel from the inner surface of the cylinder to the hole; and column 5 gives the mean speed of the thermal effect, as calculated from columns 2 and 4, that is the mean rate of thermal propagation through the metal. In each case the figures given correspond with the injection of 0·03 cubic inch of water at a temperature of about 200° Fahr. These speeds have been plotted on a curve, and are shown in Fig. 8, Plate 86.

TABLE 2.

Speed of Thermal Propagation through a Cast-Iron Cylinder Wall.

1 Thermometer Hole.	2 Thickness of intervening metal.	3 Fall of Temperature due to injection.	4 Time occupied in fall of temperature.	5 Mean Speed of thermal propagation. Per minute.
	mm. Inch.	Fahr.	Seconds.	Inches.
Steel cup	1-6 = 0·0065	25°	4	0·10
B	$1\frac{1}{2}$ = 0·06	11°	5	0·72
C	3 = 0·12	4°	6	1·20
D	6 = 0·24	1°	8	1·80
E	9 = 0·35	1°	10	2·10
F	12 = 0·47	1°	10	2·82
G	15 = 0·59	1°	9	3·93

MEMOIRS.

Alfred Evans Allen was born in London on 8th June 1846, and at an early age went to Hull. There in 1861 he was apprenticed to Messrs. Earle, shipbuilders and engineers. On the completion of his apprenticeship he remained in their employ, until in 1868 he entered the mercantile marine, and early in his career occupied important positions as an engineer on steamers in India and in the Persian Gulf. At a later period he was chief engineer of a Japanese gunboat, which he took out to Japan, remaining there a year in command. In 1880 he established himself in Hull as a consulting engineer and ship surveyor, and became superintendent engineer to Messrs. Cammell, Woolf, and Haigh, and to Messrs. Good, Flodman, and Co. In 1883 he joined Messrs. Hooper, Murrell, and Williams, as superintendent engineer, and remained with them until 1889. On the resignation of Mr. M. Allen he was appointed superintendent engineer to Messrs. Henry Briggs, Sons, and Co. Having gone to Southampton on business on 29th October 1893, he suddenly expired on board the steamship "Delos" at the age of forty-seven, from heart disease, from which he had for some time been suffering. He became a Member of this Institution in 1884; and was also a member of the Institute of Naval Architects.

Georg Maximilian Borns was born at Stettin on 18th May 1852, his father Leo Borns being at that time chief engineer on one of the mail steamers running between Stettin and Cronstadt. He was educated at Halle-on-the-Saale, and in 1866 was apprenticed to Mr. Christian Bötticher, an engineer in that town having a reputation for accurate workmanship. After serving three years he proceeded to the trade school and technical college at Halle, where he remained another three years, passing his matriculation examination in September 1871. He next went as improver into the works of Messrs. A. L. G. Dehne and Co. of Halle; and early in 1872 was appointed draughtsman and assistant manager in the works of Messrs. Kaltwasser and Co., hydraulic engineers, Halle, where he remained until 1873, when he joined the Polytechnic at Berlin. Having unfortunately from family reasons to abandon the college course, in September 1873 he came to England and was engaged as draughtsman by Messrs. Allen Ransome and Co., Chelsea, until April 1874, when he obtained an engagement with Messrs. Maw, Dredge, and Hollingsworth, first as draughtsman, subsequently as head draughtsman, and later as chief engineering assistant. In this latter capacity he had the direct supervision of a variety of work carried out under difficult circumstances and requiring the exercise of much care and judgment. In September 1891, owing to ill health, he was compelled to leave England for a less trying climate. Proceeding to New South Wales he was appointed engineer to the Shoalhaven Syndicate, to supervise the establishment of their gold-washing plant in the Shoalhaven district. Unfortunately his health did not materially improve, and although he carried out the work he had undertaken, its execution had to be followed by a prolonged rest. Ultimately, not benefitting by the climate of New South Wales, he proceeded to New Zealand, and took up his residence at Masterton, North Island, intending to devote himself for a time to agricultural pursuits; but his illness still continued, and at this place he died on 27th September 1893, in the forty-second year of his age. He became a Member of this Institution in 1892.

Joseph Breeden was born in Birmingham on 15th February 1821. In early life he was for some time in London, at the works of Messrs. Stevens and Sons, where he was instrumental in bringing out one of the first railway signals. In 1859 he invented machinery for making gas fittings, which entirely changed the system previously adopted; and in this connection he introduced the plan of obtaining the forward and backward motion of lathes by means of cross and straight bands; he also invented particular kinds of water taps and syphon cisterns. His death took place in Birmingham on 4th July 1893, at the age of seventy-two. He became a Member of this Institution in 1868.

Arthur Maudslay Brotherhood was born in London on 11th July 1867, being the eldest son of Mr. Peter Brotherhood. After working in his father's factory from October 1883 to Easter 1885, he followed the engineering course at University College under Professor Alexander B. W. Kennedy during the two sessions 1885–6 and 1886–7. He next served his time as an engineering pupil at the London and North Western Railway works at Crewe under Mr. Webb from August 1887 to August 1890; a year of this time was passed in the drawing office and in the locomotive out-door department; and he remained there as draughtsman until December 1890. In 1891 he joined his father's staff as assistant general manager, and held this position up to his death, which took place at his father's residence in London, from typhoid fever, on 6th December 1893, in the twenty-seventh year of his age. He became a Member of this Institution in 1891.

Henry Clifton Carver was born in Manchester on 21st February 1845. After leaving school he served his time with Messrs. Sharp Stewart and Co., Atlas Works, Manchester, and continued with them subsequently for a time as sub-manager. He next undertook the management of some zinc-smelting works at Bagillt; and later had some repairing works at Llanidloes. Afterwards he was in business in Manchester as a member of the firm of Messrs. Coates and Carver, engaged in buying and shipping machinery and tools to the East, especially to the Philippine Islands. He also acted frequently as a consulting engineer in connection with mechanical questions and in the preparation of patent specifications. He was the inventor of a mechanical stoker, and of an apparatus for extinguishing fires in the holds of ships by means of the waste gases from the furnaces; and also of a contrivance, which he called a "circlip," to take the place of split pins in machinery. He was at Bilbao in Spain on a business visit, when his death took place there from failure of the heart, on 6th January 1893, in the forty-eighth year of his age. He became a Member of this Institution in 1890.

James Colquhoun was born at Tollcross, near Glasgow, on 12th August 1833. He served his apprenticeship at the Clyde Iron and Steel Works, near Glasgow, and remained with that firm for about fifteen years. Subsequently he was general manager at the Llynvi and Tondu Iron and Coal Works, until in 1873 he was appointed general manager of the Tredegar Iron Coal and Steel Works, in which position he remained until his retirement in 1892. On his advice the fine coalfield connected with the Tredegar works was developed, and the blast-furnaces were remodelled. In 1882 he introduced Bessemer and rail-milling plant into the works, thus placing them on the footing of modern requirements. He was a county magistrate for Monmouthshire, and a past-president of the Coalowners' Association and of the Sliding-scale Committee, and frequently acted as arbitrator in settlement of trade disputes. His death took place at his residence at Weston-super-Mare, from paralysis followed by hemorrhage on the brain, on 20th November 1893, at the age of sixty. He became a Member of this Institution in 1884; and was also a past-president of the South Wales Institute of Engineers.

Joseph Davis was born in Manchester on 20th January 1839. In 1853 he was apprenticed to Messrs. Dunn, Hattersley and Co., Pendleton, and remained with them until the death of the surviving partner, Mr. Dunn, in 1869. He was next employed as chief draughtsman by Messrs. Wren and Hopkinson, Manchester, for whom he directed the introduction of mechanical appliances for working the heavy traffic at the Oldham Road goods station, Manchester, of the Lancashire and Yorkshire Railway, by means of iron capstans driven through shafting laid in iron troughs below the ground. Shortly afterwards he entered the service of the railway company, in charge of the bridges and machinery department under the late Mr. Sturges Meek. His first work was the goods station, Salford; and under his direction mechanical power rapidly replaced manual and horse labour throughout the goods yards and warehouses of that railway. In 1880–81 he was sent to the United States to enquire into the American system of discharging grain cargoes in bulk; the result of this journey was the construction under his direction in 1881–83 of the great grain elevator at Fleetwood, the first erected in this country on the American plan, whereby ships arriving can have their cargoes of loose grain discharged either into warehouses or weighed and delivered into carts and wagons, the whole process being done by machinery. The construction of the carriage and wagon works at Newton Heath was carried out under his charge; as was also the structural ironwork required in the extension of the railway, and the renewal and maintenance of the bridges and iron roofs of the old lines. His death took place at Chorlton-upon-Medlock, Manchester, on 15th November 1893, in the fifty-fifth year of his age. He became a Graduate of this Institution in 1876, and a Member in 1889.

James Fenton was born at Leeds on 10th November 1848. He was the only surviving son of Mr. James Fenton of Lowmoor, who was one of the earliest members of this Institution (Proceedings 1864, page 14). After being educated at St. Peter's College, York, he served his apprenticeship with Messrs. Manning, Wardle and Co., Leeds. Having passed through the various workshops and drawing office of that firm, he was employed in the locomotive department of the Great Eastern Railway and afterwards of the Midland Railway under Mr. S. W. Johnson. Subsequently he was one of the managers at Messrs. Kitson and Co.'s Airedale Foundry, Leeds. In 1883 he became one of the chief inspectors of Sir Alexander M. Rendel, under whom he had charge of the inspection of the locomotives and other railway material for the Indian State Railways, the East Indian, and other Indian lines. His death took place at Putney on 8th November 1893, in the forty-fifth year of his age. He became a Member of this Institution in 1877.

Frederick Foster was born in 1840. In 1855 he entered the drawing office and workshops in the hot-water and engineering works of Mr. J. W. Smith, Finsbury, London; and thence went to the railway-signal and gas engineering works of Messrs. Stevens and Son, Southwark. In 1860 he became engineering manager to Messrs. Scott and Co., engineers and brass founders, Whitechapel; and in 1863, having purchased their brass foundry, he carried on this portion of the business on his own account. In 1868 he became manager to Mr. Sampson Barnett, Hoxton, with whom in 1870 he entered into partnership in the firm of Messrs. Barnett and Foster; and he devoted his attention to the improvement of aerated-water machinery. On Mr. Barnett's retirement in 1884, he became sole proprietor of the business; and was associated with Mr. Codd in the manufacture and introduction of their peculiar bottles bearing that name. His death took place at his residence in Holloway on 4th March 1893, at the age of fifty-three. He became a Member of this Institution in 1886.

Richard Henesey was born in County Cavan, Ireland, on 25th February 1837. From 1851 to 1858 he served an apprenticeship with Messrs. W. G. Armstrong and Co., Elswick Engine Works; after which he remained there for three years as a journeyman. In 1862 he went to the United States, and was employed for four years and a half at the Providence Engine Works, Rhode Island, of which he became foreman, and was principally engaged in charge of erecting machinery and engines there, and at Boston and New York. On the closing of the works in 1868 he returned to England, but soon left for Bombay, where he became manager of Messrs. Fraser and Miller's Carnac Iron Works. In 1870 he was appointed superintending engineer to Messrs. Nicol and Co., Byculla Iron Works, Bombay, and afterwards to their successors, Messrs. Richardson and Cruddas, at the same works. After having held that position for thirteen years, in March 1883 he entered into partnership with Messrs. Donald and Couper, under the name of Messrs. Donald, Henesey, and Couper, Ripon Iron Works, Bombay; but in December 1884 he retired from the firm, and returned to England shortly afterwards. After spending three years at Uxbridge, he went out again to Bombay in 1888, and became general manager to Messrs. Gahagan and Co. up to the time of his death, which took place at Bombay on 21st September 1892, in the fifty-sixth year of his age. He became a Member of this Institution in 1878.

Charles James Homer was born at Hanley on 17th August 1837, and was a pupil under Mr. William Forshaw at Earl Granville's collieries and ironworks from 1852 to 1856, when the development of the collieries and the erection of rolling mills and blast-furnaces was being proceeded with. Subsequently he entered into general practice as a mining engineer and surveyor; and in 1864 became general manager of the Chatterley ironstone mines at Tunstall. In 1871 he joined some local gentlemen in the formation of the Chatterley Coal and Iron Co., of which he became the managing director. Blast-furnaces were erected, the mines further developed and additional collieries acquired, including the Whitfield Colliery, for which a private line of railway over two miles long was constructed to connect them with the towns of Tunstall and Burslem; the colliery has since proved one of the most productive and valuable in Staffordshire. In 1871–2 the Longton, Adderley Green, and Bucknall Railway, about five miles in length, constituting a loop of the North Staffordshire Railway for opening out the collieries in the Adderley Green Valley, was constructed under his direction as engineer; this is now worked by the North Staffordshire Railway, and serves several collieries which were previously land-locked. In 1873 he became connected with the late Duke of Sutherland, Sir John Pender, and Mr. Bourne in the development of the Stafford Coal and Iron Works adjoining the Trentham estates. This was virgin ground which had not been proved, and was thought by some to be outside the limits of the North Staffordshire coalfield; but on his advice shafts were put down and the upper measures proved. Permanent shafts were sunk and the most improved mining plant erected and laid out under his superintendence. At these collieries he introduced pit-head frames constructed entirely of iron. In 1880 he undertook the development of the mines at the Ivy House, Hanley, which are now one of the chief sources of supply to the town of Hanley. On his advice and with his assistance the Norwich Union Life Insurance Society reopened the collieries at Clough Hall, Kidsgrove, which were subsequently taken over by Mr. Robert Heath. It is estimated that by this operation alone upwards of twenty million tons of fuel were secured from abandonment. He was also in practice as a consulting engineer; and owing to his extensive knowledge of the geology of the district, he was consulted respecting the development of most of the mines in the neighbourhood, and also of some abroad. His health had not been good for some time previous to his death, which took place at his residence, the Ivy House, Hanley, on 4th November 1893, at the age of fifty-six. He became a Member of this Institution in 1867; and was one of the founders of the North Staffordshire Institute of Mining and Mechanical Engineers, of which he was president in 1874 and 1875.

Alfred Longsdon was born on 22nd May 1827. In 1845 he entered the service of Mr. Alfred Krupp of Essen, who employed him at first in connection with English patents. In 1856 he was appointed the firm's representative in London for Great Britain; and in 1873 became one of the directors in Essen, at the same time retaining his position of manager of the London office. As a director he shared the conduct of the business, and took a prominent part in many of the alterations and additions which have been carried out in the cast-steel works at Essen and in the blast-furnaces and mines belonging thereto. For this purpose he annually spent several months there at regular intervals up to four or five years ago. His sound judgment, practical views, and great experience were highly valued both by the late Mr. Alfred Krupp and by the present proprietor of the firm, Mr. Friedrich Alfred Krupp, and by his colleagues in the direction. Some twenty years ago he took part on behalf of the Essen firm, together with several English and Spanish firms, in the purchase of some Spanish iron ore mines, and in the formation of the Orconera Iron Ore Co. for working them, of which he was managing director in London. His death took place at his residence at Denmark Hill, London, on 27th November 1893, in the sixty-seventh year of his age. He became an Associate of this Institution in 1865.

Daniel Macnee, second son of Sir Daniel Macnee, who was President of the Royal Scottish Academy, was born in Glasgow on 23rd April 1838, and was educated in Glasgow and in Dumfries-shire.

After serving an apprenticeship as a mechanical engineer for five years to the firm of Messrs. Smith and Rodger, marine-engine builders, Glasgow, he commenced in 1858 a pupilage as a civil engineer under Mr. Edward Wilson, engineer to the West Midland Railway, Worcester, and was engaged on the construction of various branch lines, and of the railway between Honeybourne and Stratford-on-Avon. In 1862 he was appointed resident engineer and district superintendent of the Newport Abergavenny and Hereford section of the West Midland Railway. During the time he held that post the Taff Vale extension to Mountain Ash and several other branches were constructed under his superintendence. In 1864 he entered the service of Messrs. Charles Cammell and Co., Sheffield, as their engineer; and during the four years he remained with them he erected new works at Penistone and Grimesthorpe. In 1868 for the Royal Commission on Irish Railways he valued and reported upon the whole of the workshops, machinery, engines, and rolling stock of all the railways south of Dublin. In 1869 he entered into partnership with the firm of Messrs. Joseph Armstrong and Co., Rotherham, manufacturers of railway points and crossings, and ironwork for permanent way and for rolling stock. In 1877 he commenced practice as an engineer and contractor in Rotherham, where he was engaged first in planning and laying out the Sandiacre Wagon Works near Trent; and afterwards in 1879 in designing and building the railway points and crossing department of the Anderston Foundry Co.'s works at Port Clarence near Middlesbrough. In 1880 he removed to Westminster, where he acted as representative of the Anderston Foundry Co. Among his inventions was a throw-over lever-box for actuating railway points; and a railway axle-box, from which the dust was excluded by a sliding metallic ring at the back of the box, pressed lightly into contact with the nave of the wheel. Towards the end of 1892 he had an attack of blood-poisoning, followed by dropsy; and after an illness of more than six months he died on 30th June 1893, at the age of fifty-five. He became a Member of this Institution in 1865.

WILLIAM RODGER was born at Barrhead, near Glasgow, in 1843. He served his apprenticeship with Messrs. Blackwood and Gordon, Port Glasgow. In 1865 he went out to India in the service of the British India Steam Navigation Co. In 1874 he was in the employ of Messrs. Jules Siegfried and Co. as engineer of a cotton press at Kattiawar; and afterwards superintending engineer for the Sassoon Press Co. in Bombay. In 1876 he went home to Glasgow, returning to Bombay in 1879, where he commenced business as a consulting engineer and machinery agent. At the end of 1881 he became engineer to Messrs. Ralli Brothers' cotton press and ginning factories in the Berars; which appointment he held until 1884, when he had to leave India on account of ill health. He remained in Glasgow until 1888, when he again returned to India as engineer in Khandesh for Messrs. Gaddum Bythell and Co. Latterly he was in the employ of Messrs. Volkart Brothers in their flour mill at Delhi, with whom he remained until his death, which took place in a railway carriage at Jeypore, on his way from Delhi to Bombay, on 15th March 1893, at the age of fifty. He became a Member of this Institution in 1879.

WILLIAM STRINGER was born at Blacklion, County Carlow, Ireland, in 1852. At the age of sixteen he entered the service of Messrs. E. Shackleton and Sons, millers, Carlow, to whom afterwards he was apprenticed. In 1878 he had complete charge of the mill; and during the substitution in 1880 of roller milling machinery in place of millstones by Mr. Henry Simon of Manchester, he made various suggestions which were found to be of practical use. In 1881 he entered Mr. Simon's service, and ultimately became head of one of the departments. Besides being a thorough miller, he had a mechanical bent, which, united with great care in detail, enabled him to grasp clearly in every part the construction and working of the largest mill. His death took place after a brief illness at Chorlton-cum-Hardy, Manchester, on 5th November 1893, at the age of forty-one. He became a Member of this Institution in 1891.

Ralph Teasdale Walker was born at Sourabaya, Java, on 10th November 1864. Coming to England when nine years of age, he was educated at Brighton Grammar School and Dulwich College. At the age of nineteen he was articled as pupil at the works of Messrs. Eastons and Anderson, Erith, and went through the general routine of the works and drawing office for three years and a half. On leaving in 1887 he was engaged for one year by Messrs. W. and A. McOnie, Glasgow, and afterwards by Messrs. Robey and Co., Lincoln, with the object of gaining a varied experience. He was next employed for one sugar-making campaign at the Gastel beetroot sugar factory, near Rosendaal, Holland, where he acquired the preliminary knowledge which enabled him in a great measure to grasp the intricacies of the manufacture of sugar. In February 1889 he went to Java, and was appointed first engineer in the Olean sugar factory, Sitoebondo, where he erected a complete new plant of sugar-making machinery of most modern design and construction, having a capacity of 1,200 to 1,500 tons of marketable sugar per month, and worked it through the following campaign. After this he was appointed first engineer at the Seragie sugar factory, Pekalongan; but during the first campaign of 1893 he was stricken with virulent fever, and after four days' illness died there on 14th November 1893, at the age of twenty-nine. He became a Graduate of this Institution in 1884.

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CLEVELAND INDUSTRIES.

Blast Furnaces at Ormesby Iron Works.

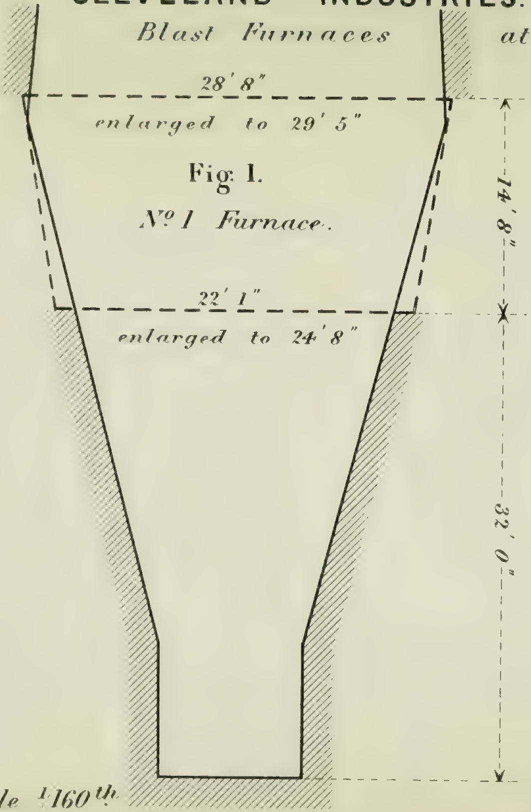


Fig: 1.

No 1 Furnace.

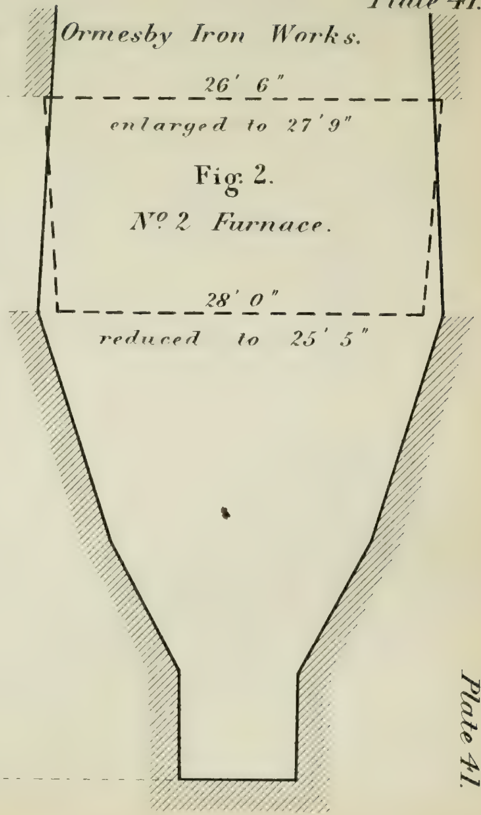
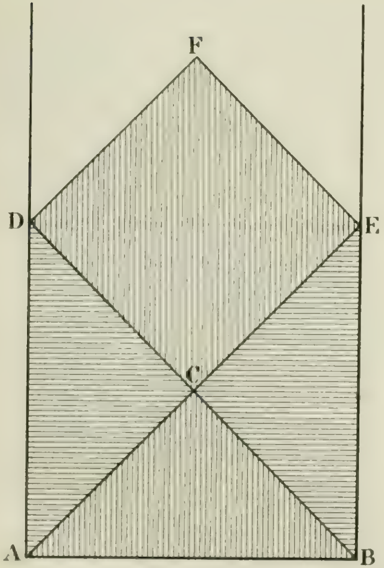


Fig: 2.

No 2 Furnace.

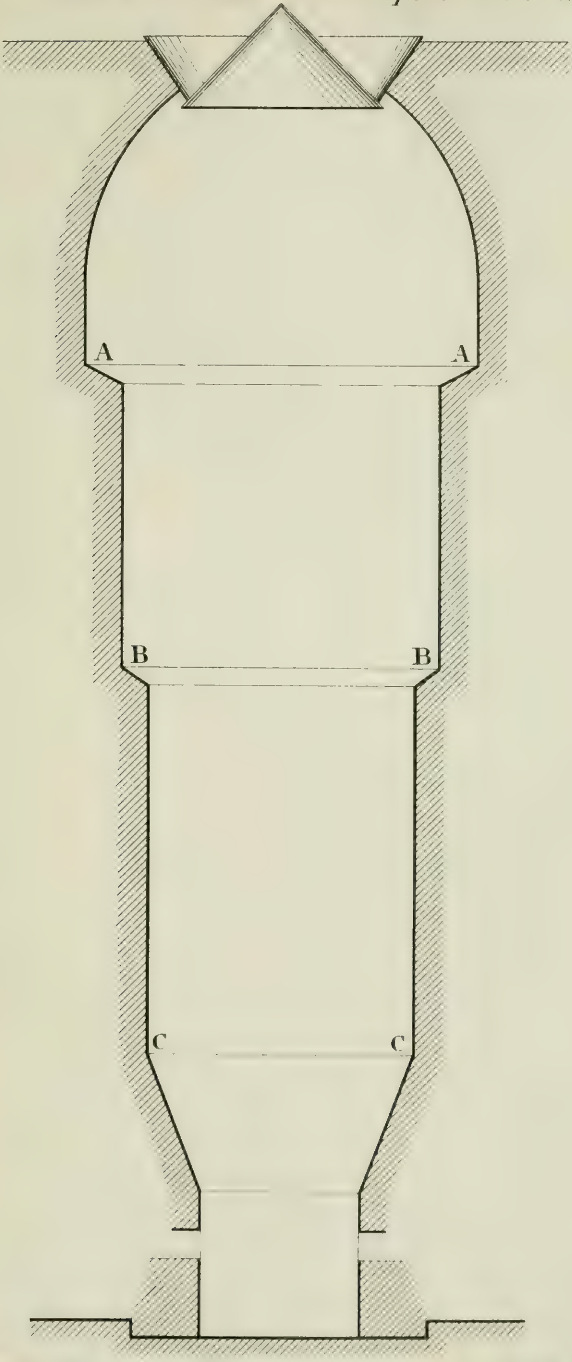
Fig: 3.



Mechanical Engineers 1893.

Scale 1/160th.

Fig. 4. *Blast Furnace at Newport Iron Works.*



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MIDDLESBROUGH SALT INDUSTRY.

Fig. 1. *Plan of Salt District.*

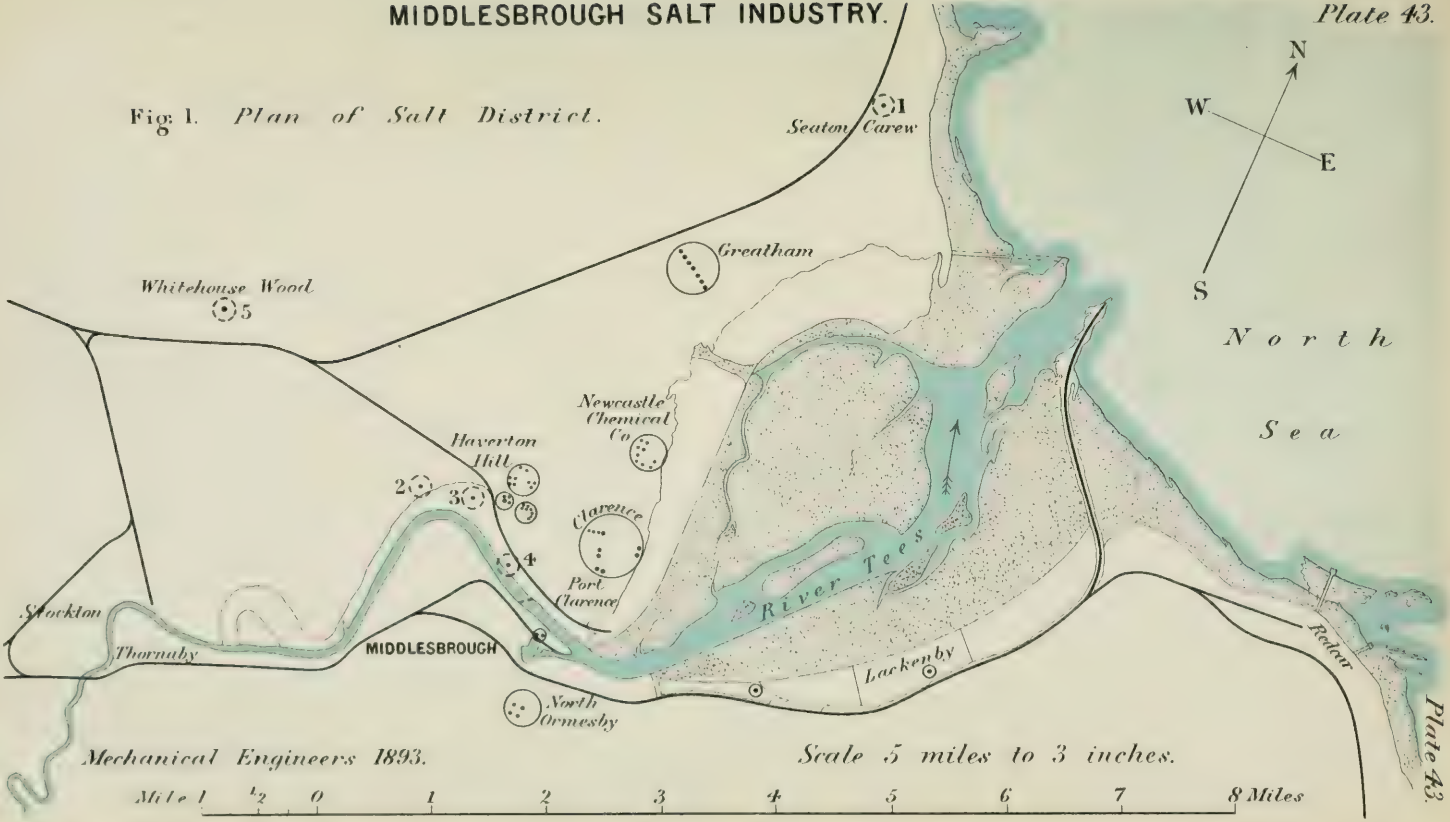


Plate 43.

Drilling and Pumping Derrick.

Fig. 2. *Elevation.*

Scale 1/200 th.

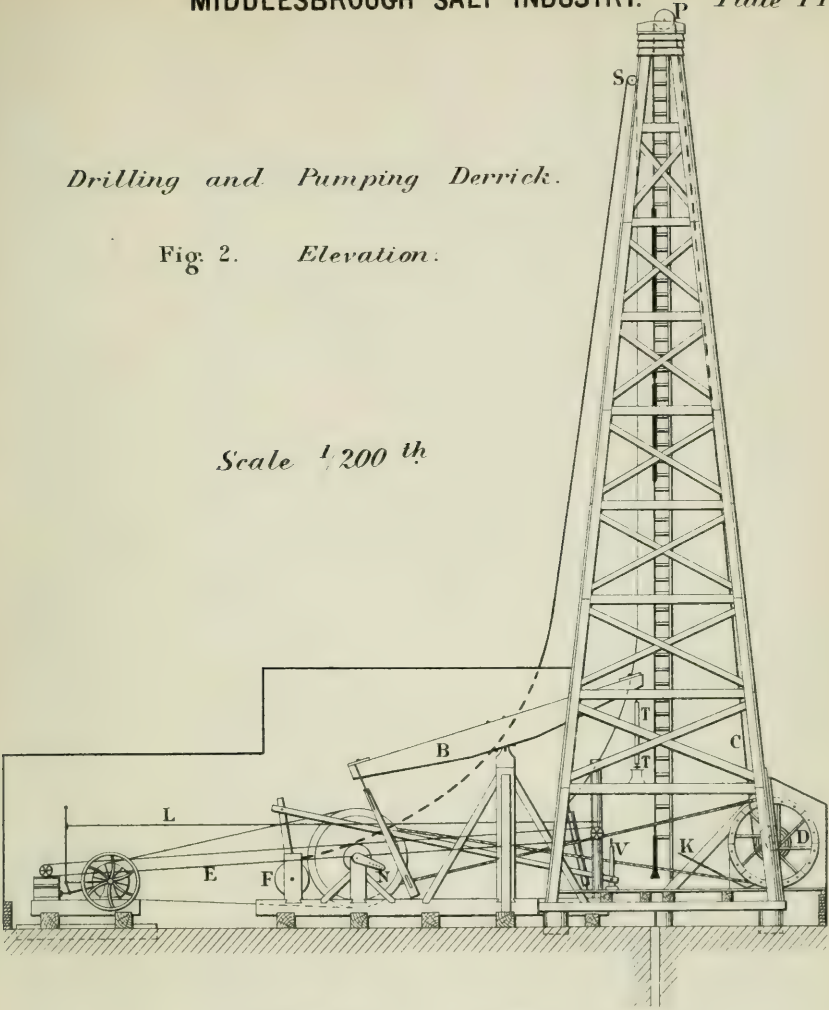
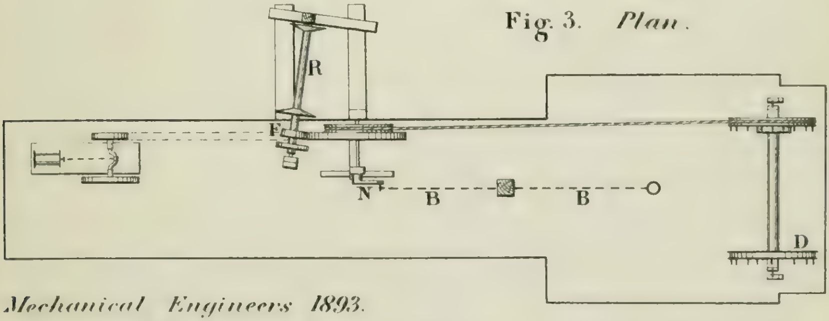
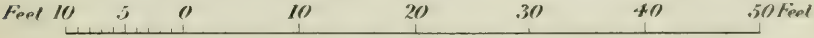


Fig. 3. *Plan.*





MIDDLESBROUGH SALT INDUSTRY. *Plate 45.*

Fig. 4.
String of Tools.
Scale 1/60th.

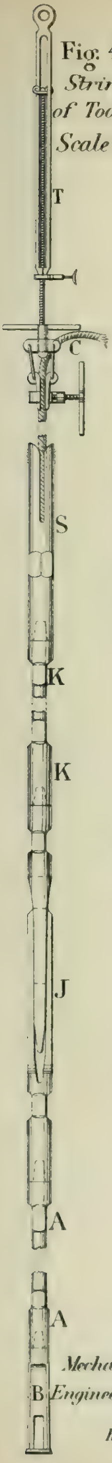
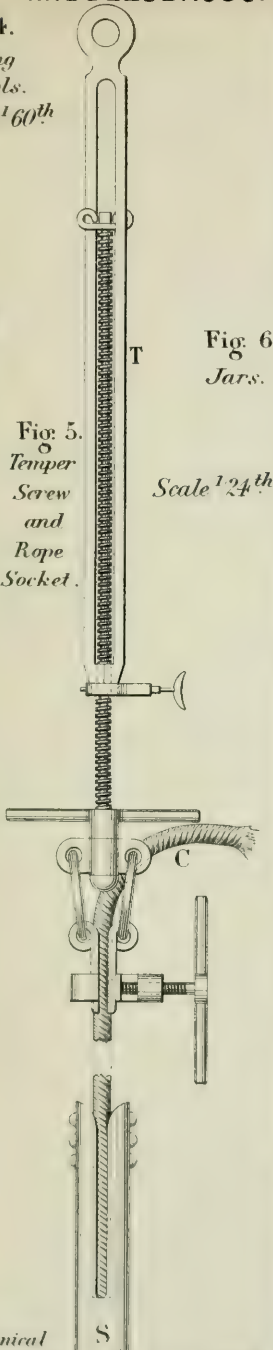


Fig. 5.
Temper Screw and Rope Socket.



Scale 1/24th.

Fig. 6.
Jars.

Scale 1/24th.

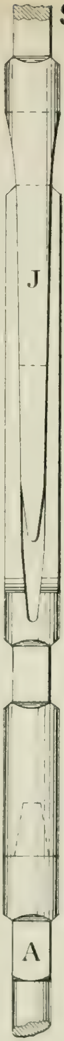


Fig. 7.
Chisel.

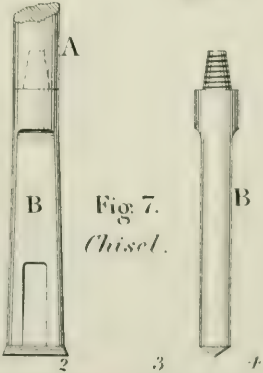


Fig. 8.
Screw-joint.
Scale 1/12th.

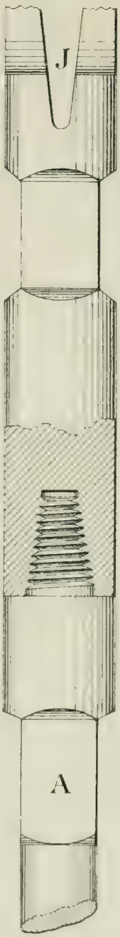
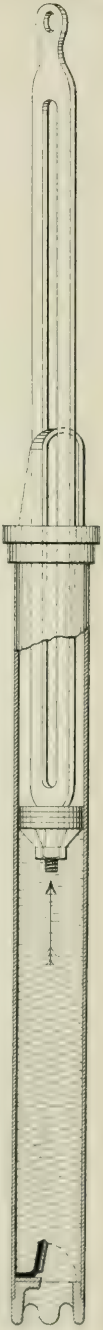
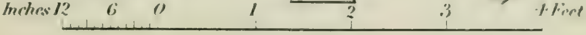


Fig. 9.
Sand-pump.
Scale 1/16th.



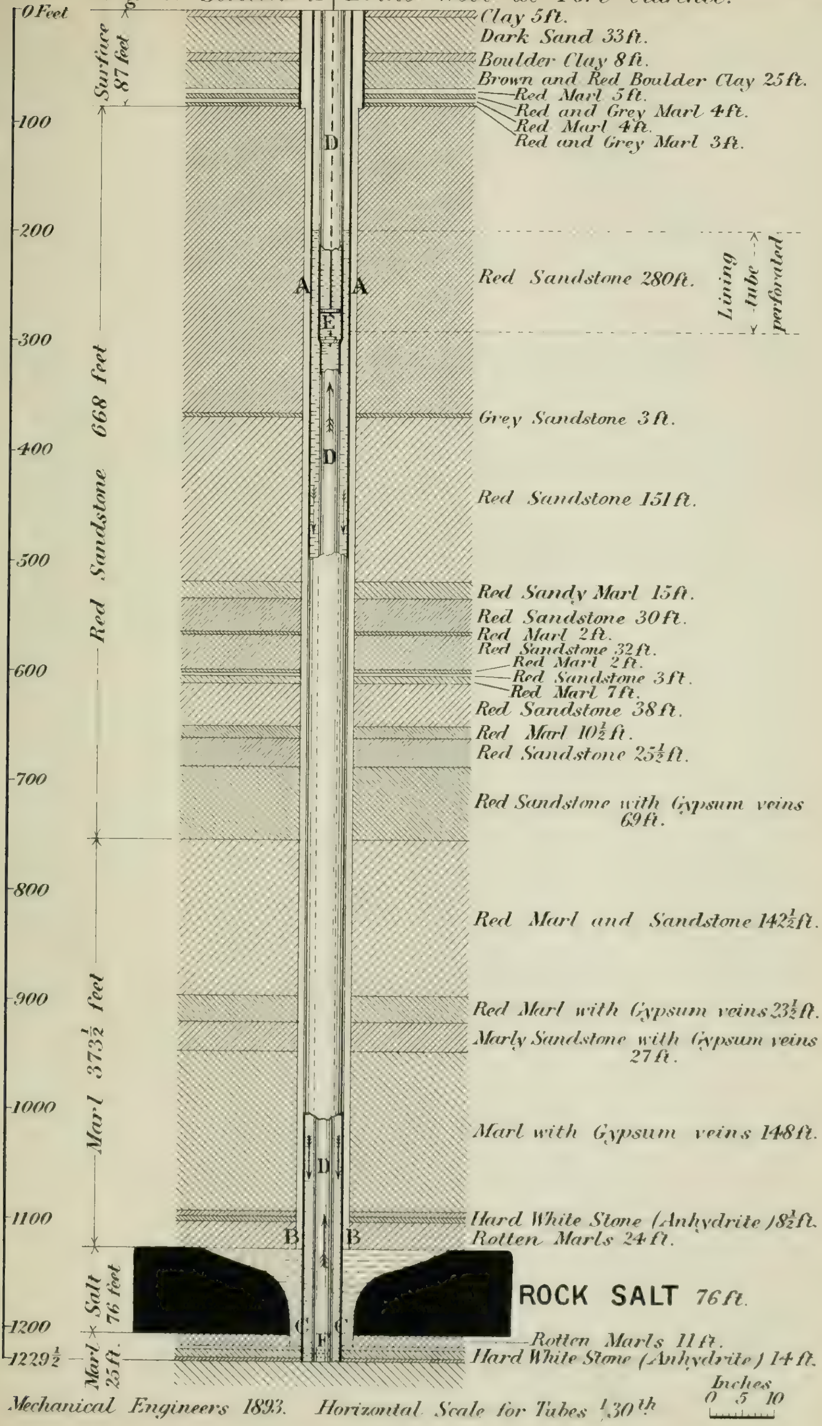


Mechanical Engineers 1893.

MIDDLESBROUGH SALT INDUSTRY.

Plate 46.

Fig: 10. *Section of Brine Well at Port Clarence.*



Mechanical Engineers 1893. *Horizontal Scale for Tubes 1/30th.*

Evaporation of Brine.

Fig: 11.

Transverse Section of Salt-Pan and Hurdles.

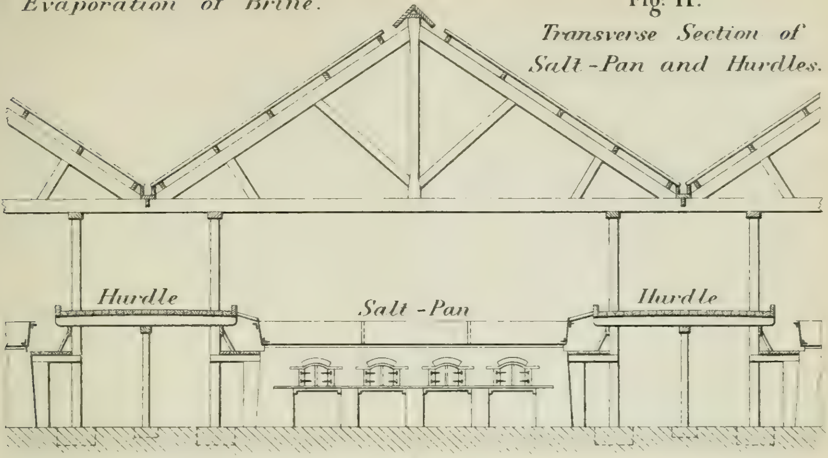
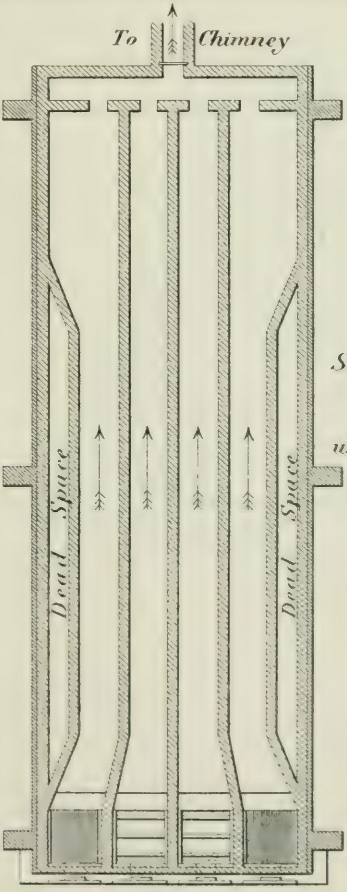


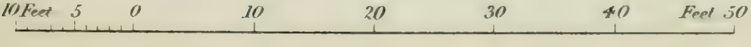
Fig: 12.

Sectional Plan of Flues under Salt Pan.



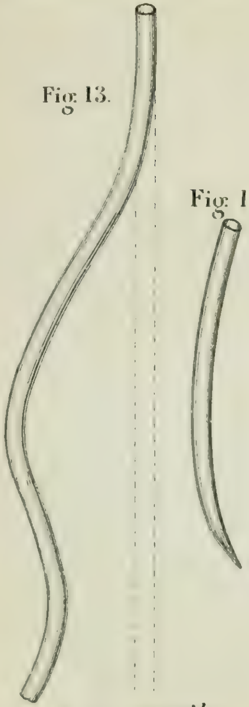
Mechanical Engineers 1893.

Scale 1/200th



MIDDLESBROUGH SALT INDUSTRY.

Broken Suction-Tubes.



Scale 1/40th

Fig. 15. *Ideal Section of new Well before Fall of Roof.*

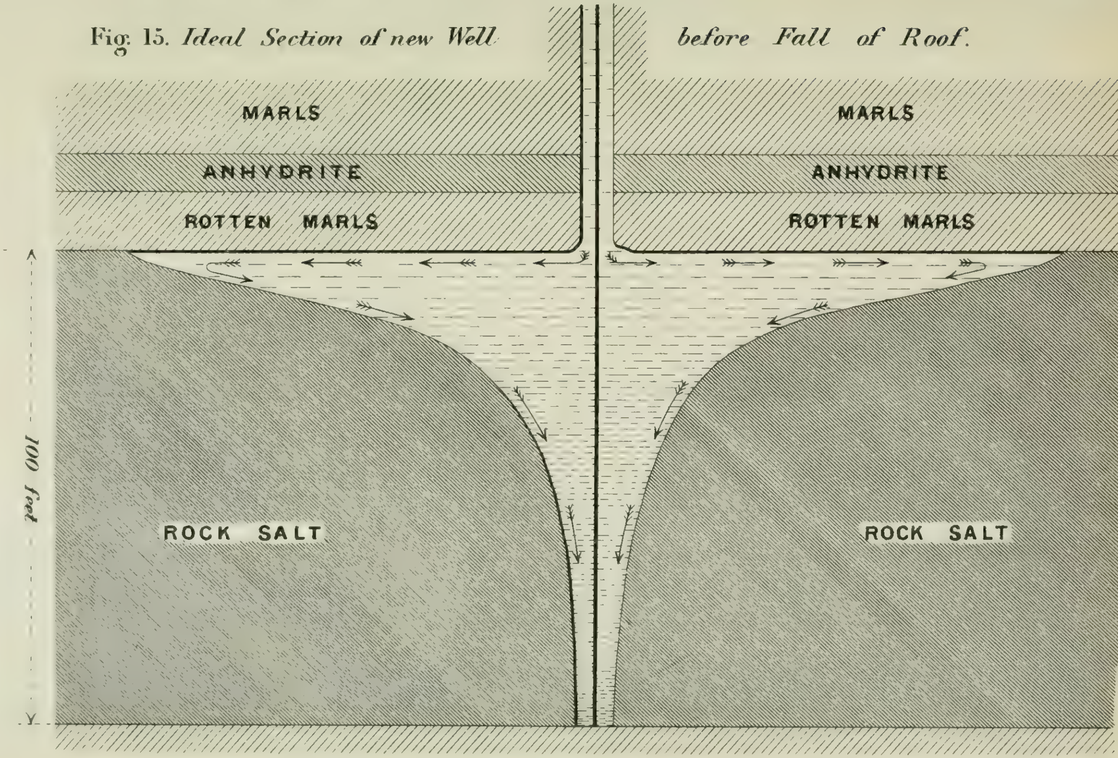
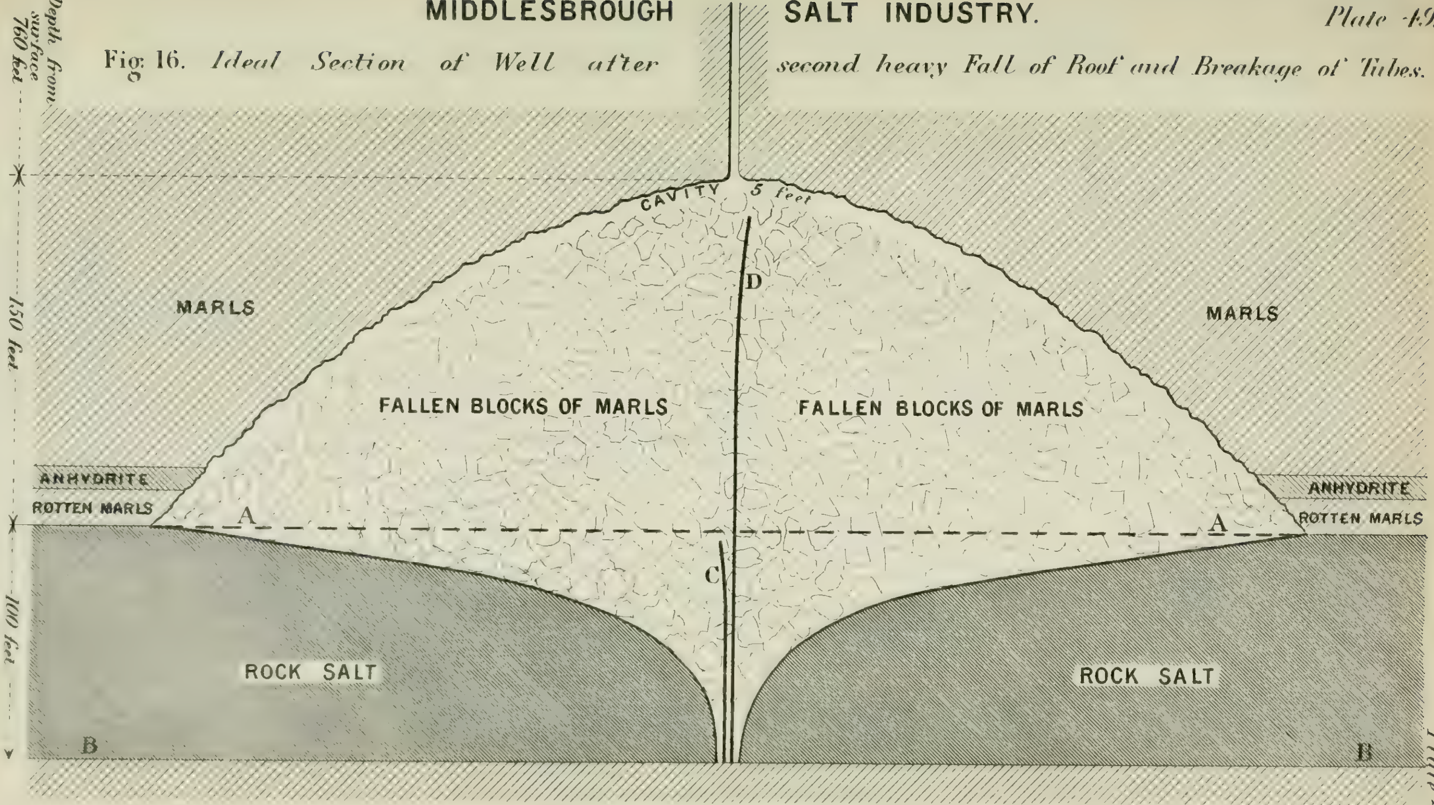


Plate 48.

MIDDLESBROUGH SALT INDUSTRY.

Fig. 16. *Ideal Section of Well after second heavy Fall of Roof and Breakage of Tubes.*



ELECTRIC ROCK-DRILL.

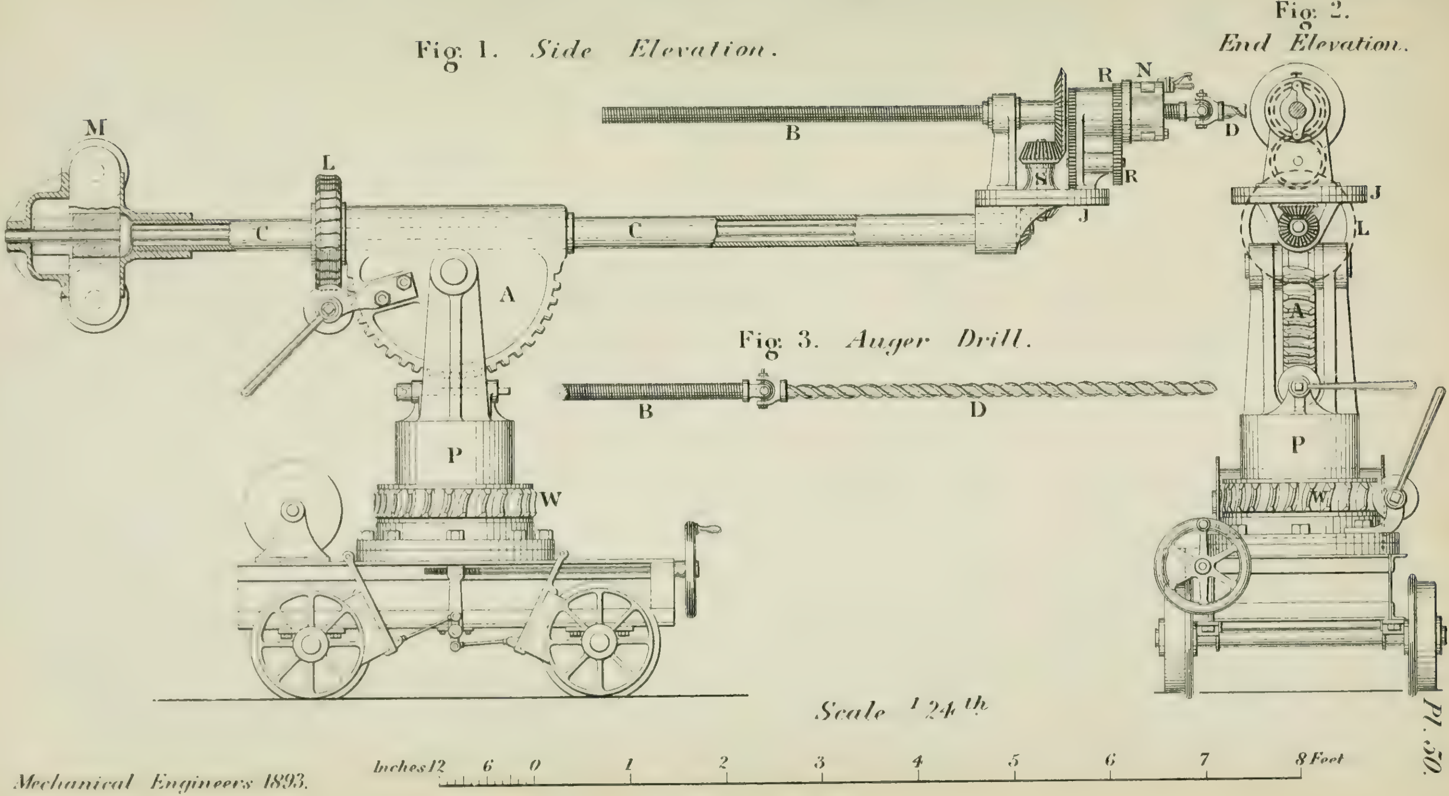


Fig: 1. *Side Elevation.*

Fig: 2. *End Elevation.*

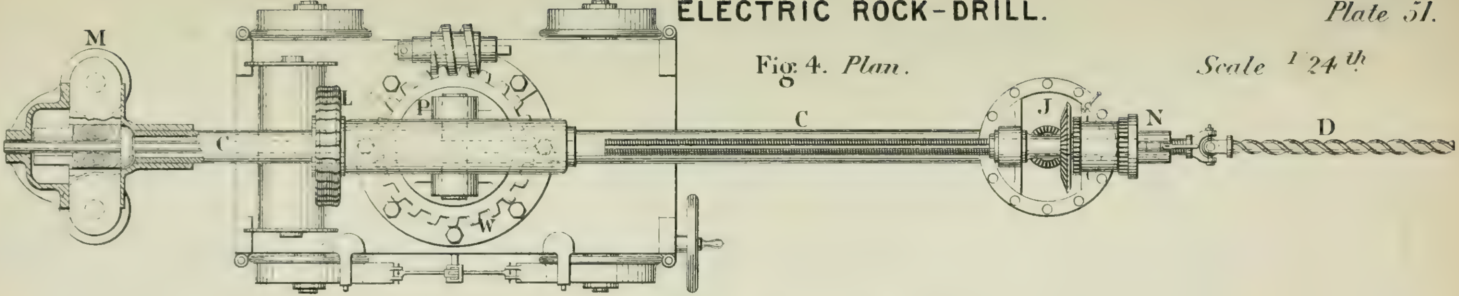
Fig: 3. *Auger Drill.*

Scale 1/24th

ELECTRIC ROCK-DRILL.

Fig: 4. *Plan.*

Scale $^1/_{24}{}^{th}$.



Split Nut of Feed Gear.

Fig: 5.
Nut closed.

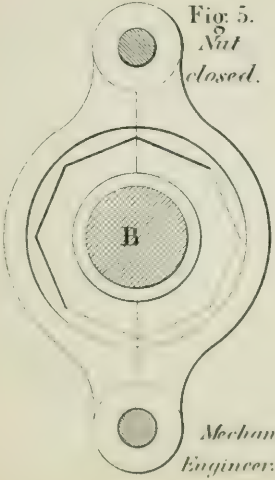


Fig: 6.

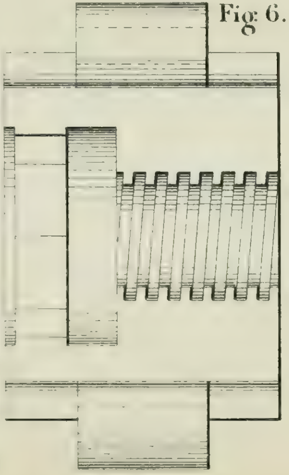


Fig: 7.

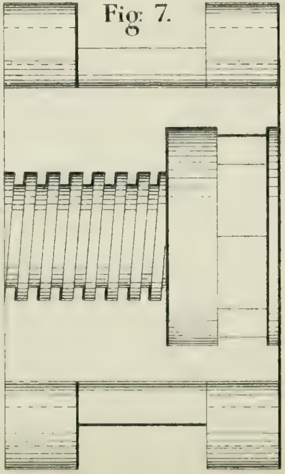
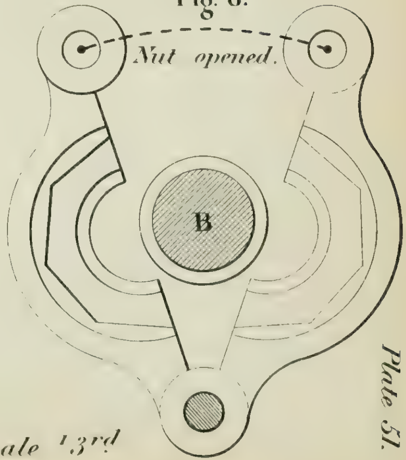


Fig: 8.
Nut opened.



Scale $^1/_{3}{}^{rd}$.

Mechanical Engineers 1893.

ELECTRIC ROCK-DRILL.

Forward Feed of Boring Bar.

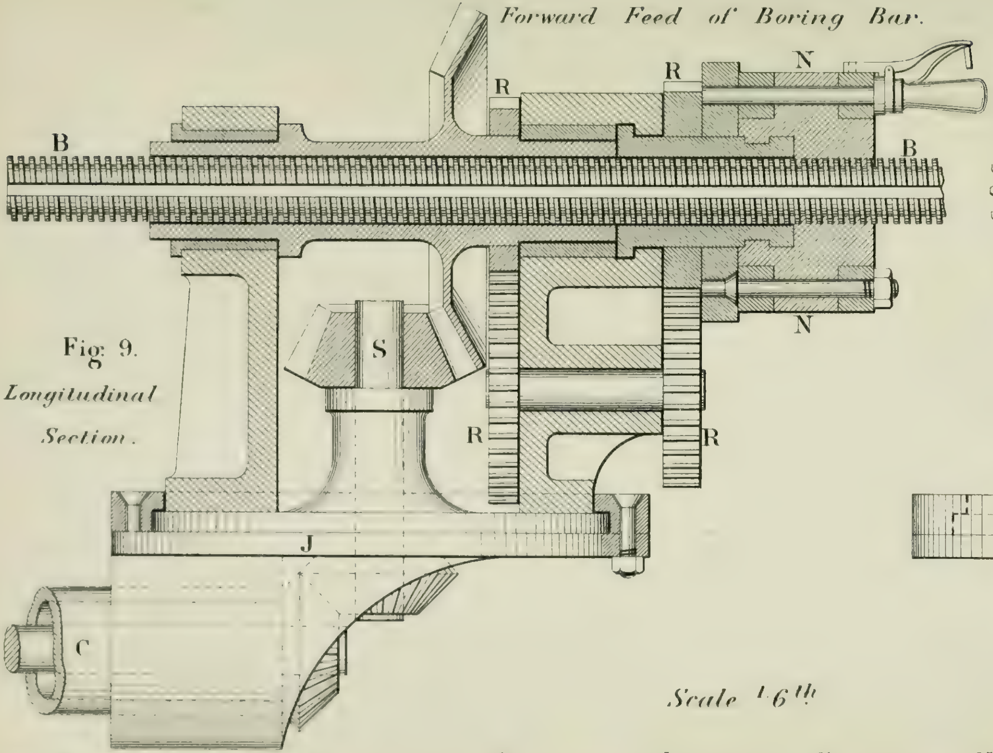


Fig: 9.

Longitudinal Section.

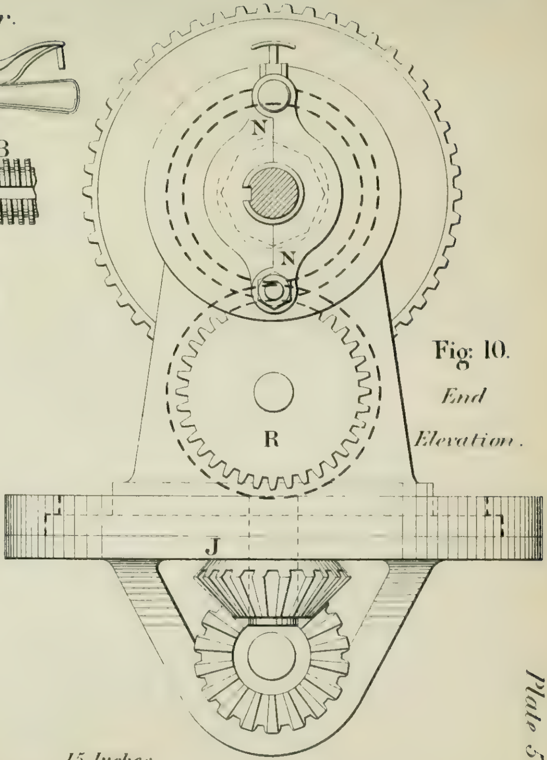


Fig: 10.

End Elevation.

Scale 1/6th

0 5 10 15 Inches

Mechanical Engineers 1893.

ELECTRIC ROCK-DRILL.

Junction - Box.

Connecting-Plug withdrawn.

Fig. 11. *Elevation.*

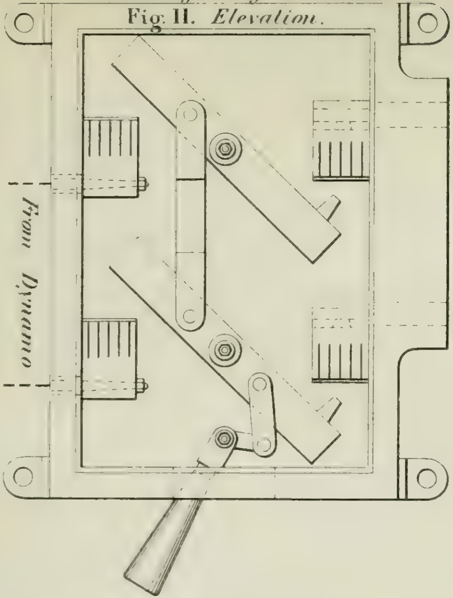
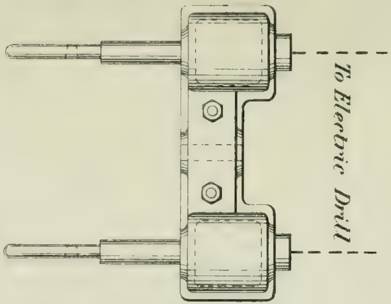


Fig. 14. *Elevation of Connecting-Plug.*



Connecting-Plug locked.

Fig. 12. *Elevation.*

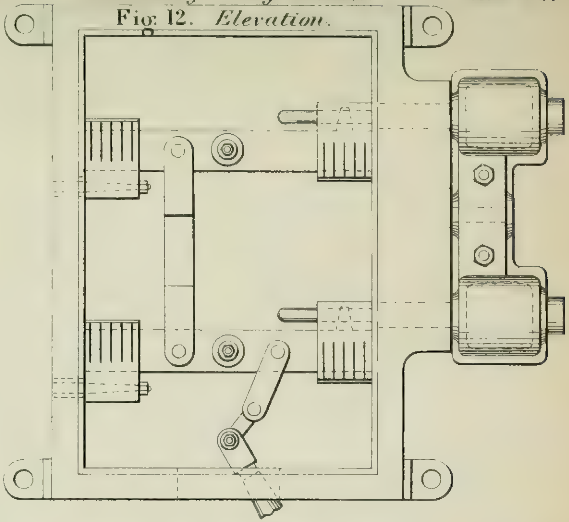


Fig. 13. *Plan inverted.*

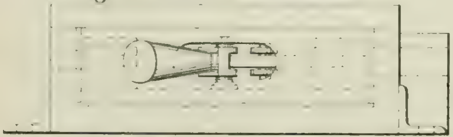
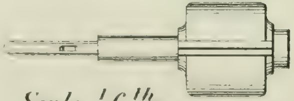


Fig. 15. *Plan of Connecting-Plug.*



Scale 1/6th

0 2 4 6 8 10 12 *Inches*

Detail of Contacts.

Half size.

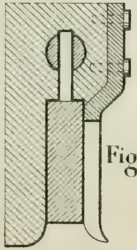


Fig. 16.

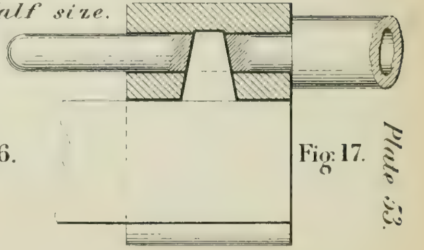
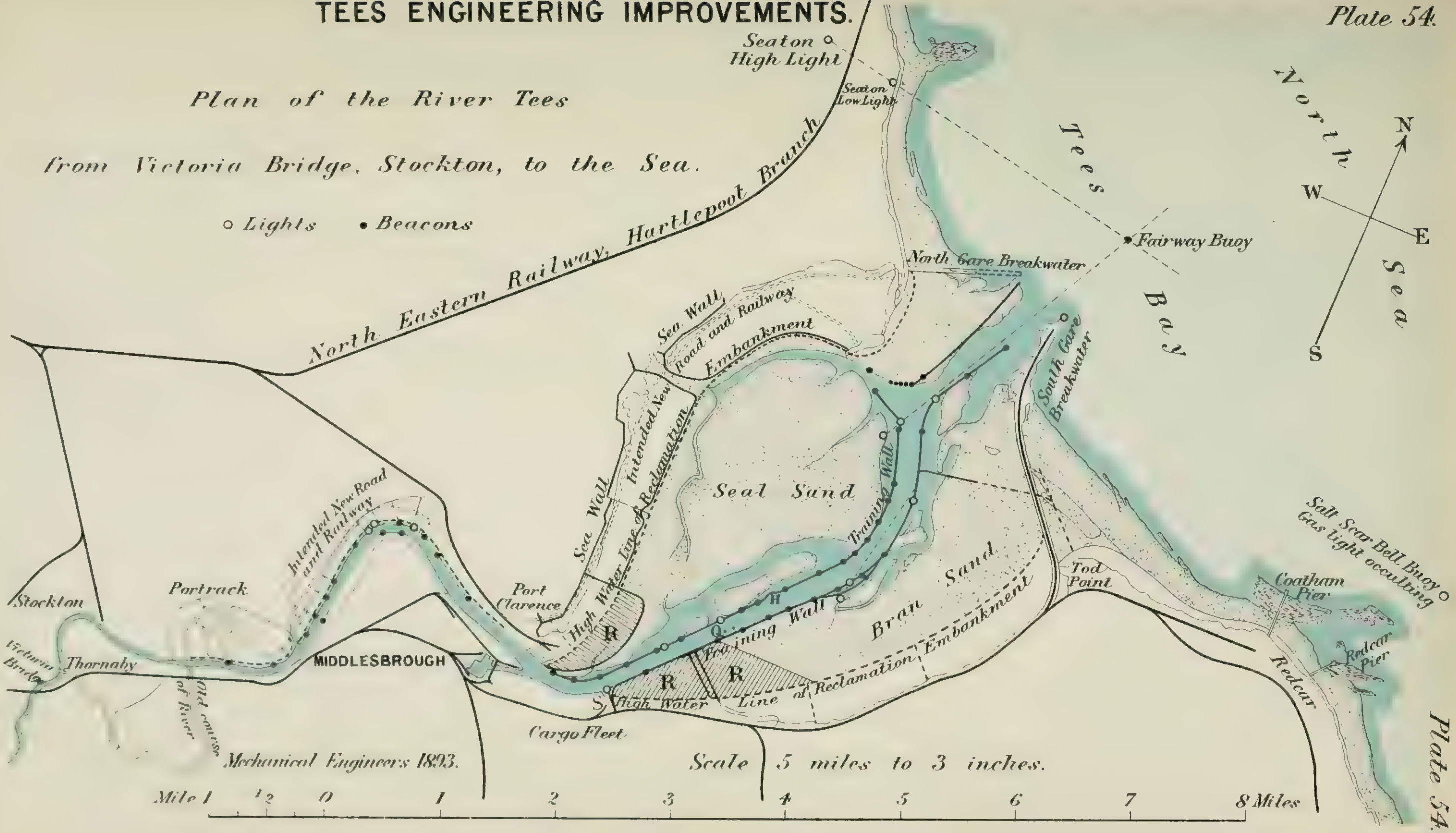


Fig. 17.

TEES ENGINEERING IMPROVEMENTS.

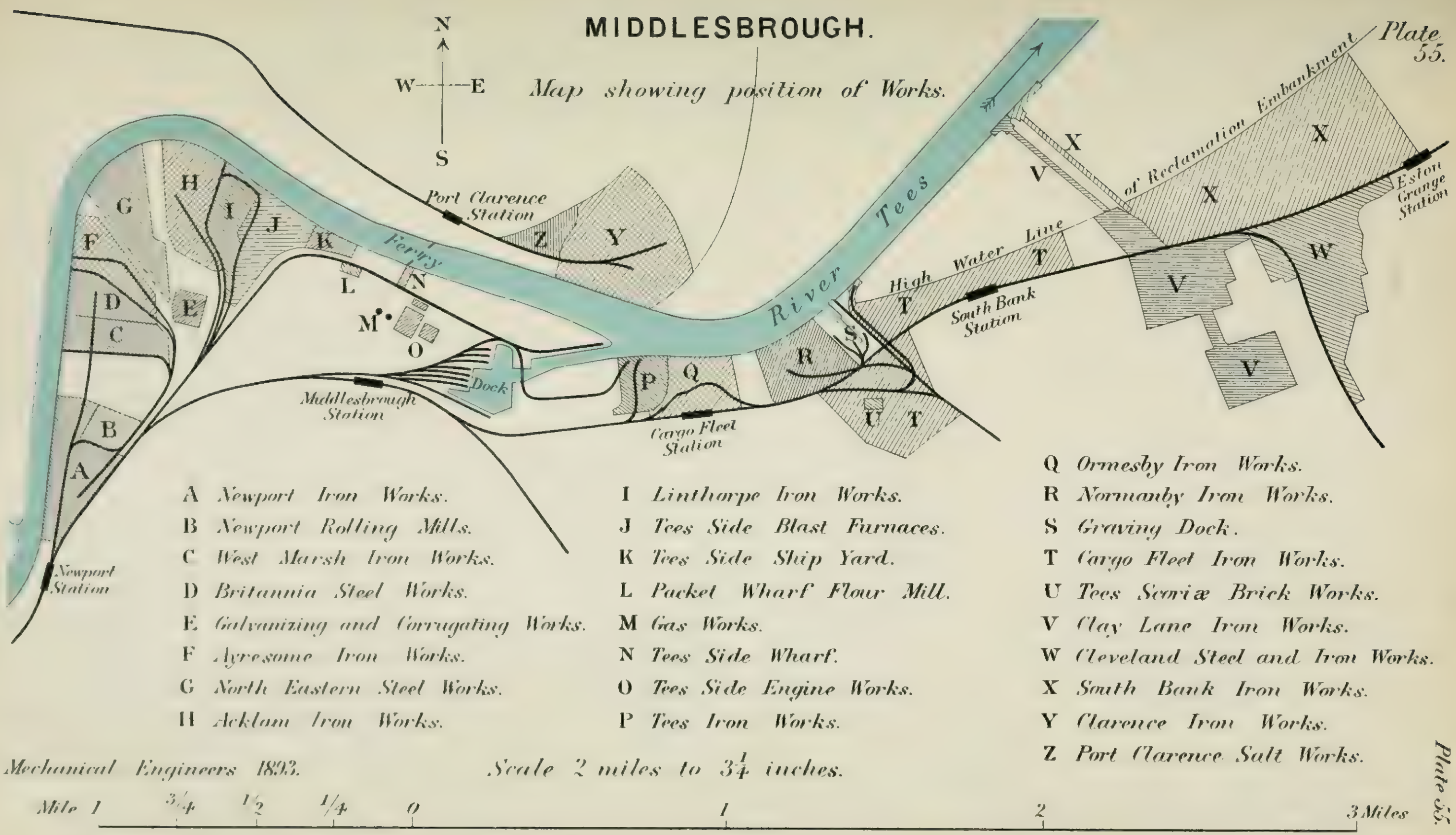
Plan of the River Tees

from Victoria Bridge, Stockton, to the Sea.



MIDDLESBROUGH.

Map showing position of Works.



A Newport Iron Works.
B Newport Rolling Mills.
C West Marsh Iron Works.
D Britannia Steel Works.
E Galvanizing and Corrugating Works.
F Ayresome Iron Works.
G North Eastern Steel Works.
H Acklam Iron Works.

I Linthorpe Iron Works.
J Tees Side Blast Furnaces.
K Tees Side Ship Yard.
L Packet Wharf Flour Mill.
M Gas Works.
N Tees Side Wharf.
O Tees Side Engine Works.
P Tees Iron Works.

Q Ormesby Iron Works.
R Normanby Iron Works.
S Graving Dock.
T Cargo Fleet Iron Works.
U Tees Scoriæ Brick Works.
V Clay Lane Iron Works.
W Cleveland Steel and Iron Works.
X South Bank Iron Works.
Y Clarence Iron Works.
Z Port Clarence Salt Works.

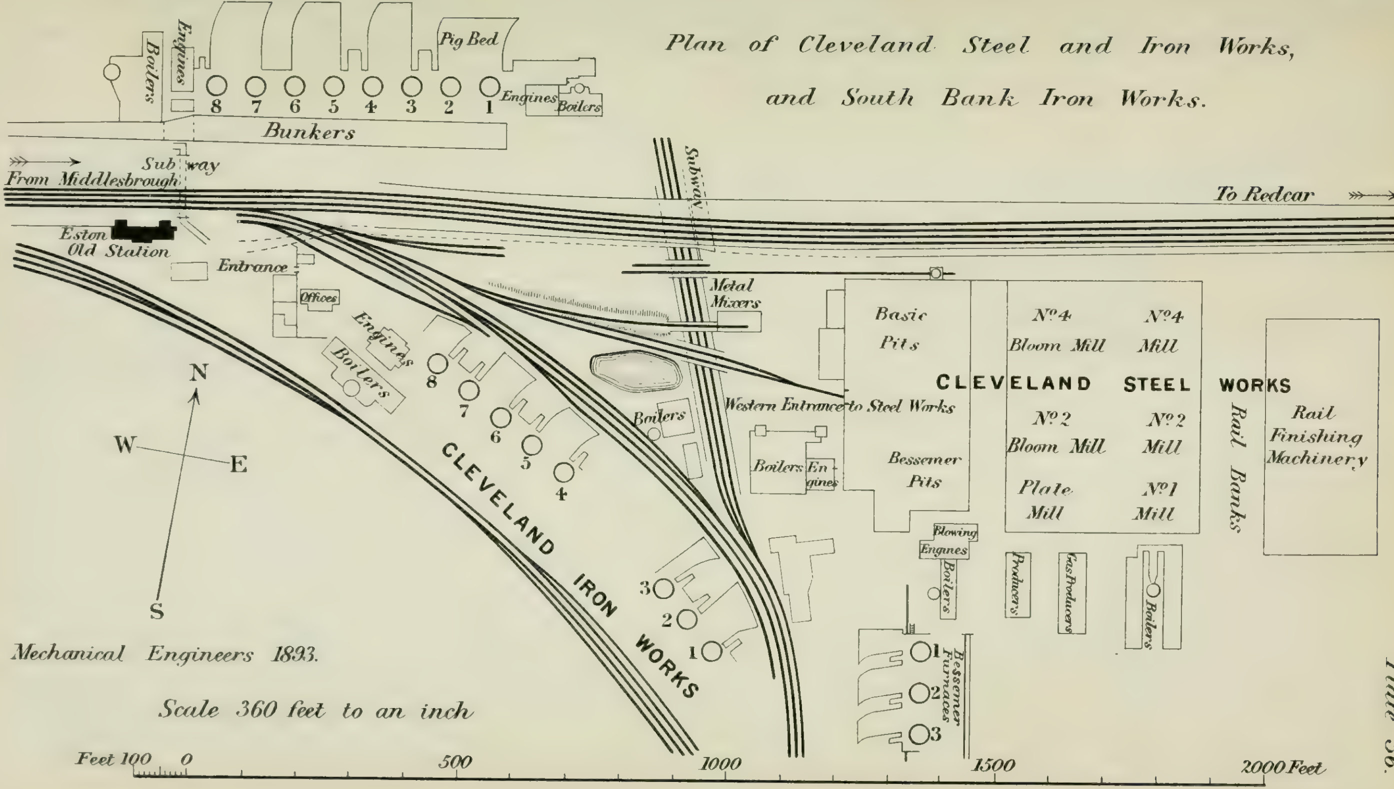
Mechanical Engineers 1893.

Scale 2 miles to $3\frac{1}{4}$ inches.

STEEL AND IRON WORKS.

Plan of Cleveland Steel and Iron Works,

and South Bank Iron Works.

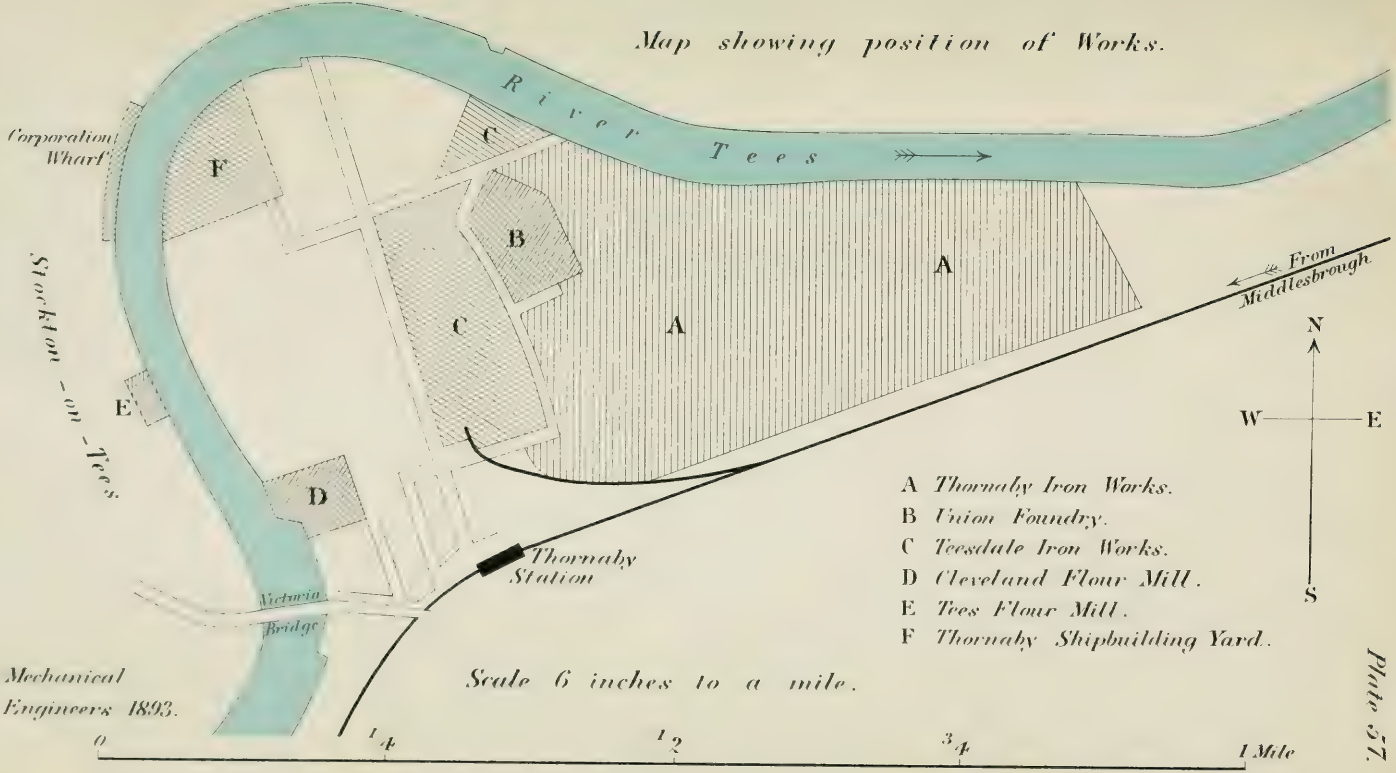


Mechanical Engineers 1893.

Scale 360 feet to an inch

THORNABY.

Map showing position of Works.



A Thornaby Iron Works.
B Union Foundry.
C Teesdale Iron Works.
D Cleveland Flour Mill.
E Tees Flour Mill.
F Thornaby Shipbuilding Yard.

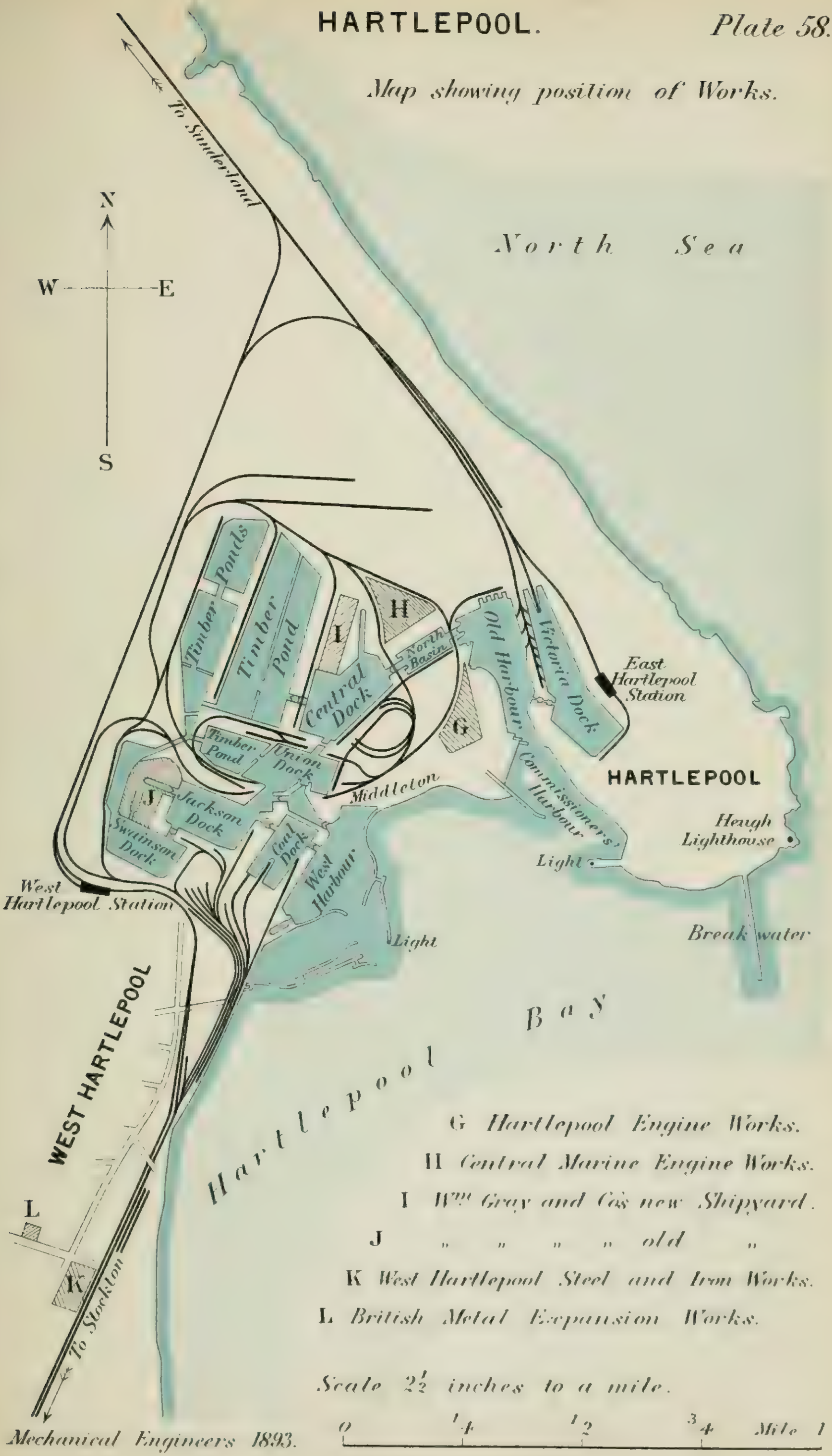
Scale 6 inches to a mile.

Mechanical
Engineers 1893.

HARTLEPOOL.

Plate 58.

Map showing position of Works.

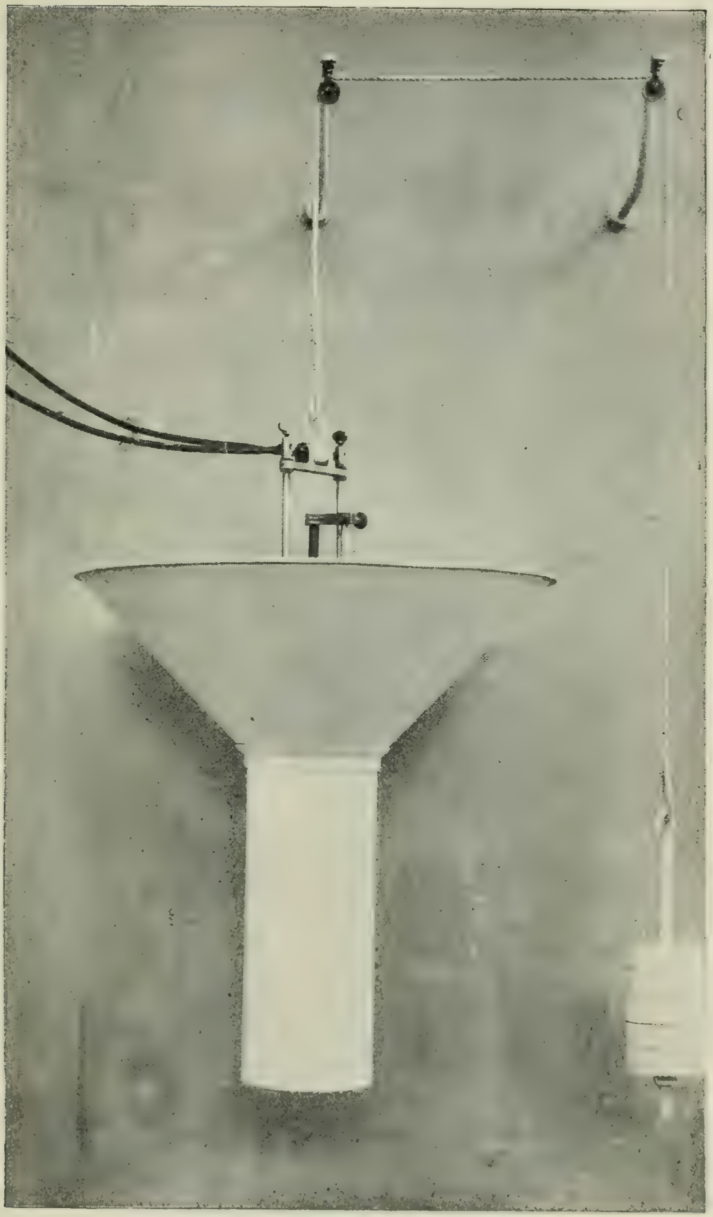


G	*Hartlepool Engine Works.*
H	*Central Marine Engine Works.*
I	*Wm Gray and Co's new Shipyard.*
J	„ „ „ „ *old* „
K	*West Hartlepool Steel and Iron Works.*
L	*British Metal Expansion Works.*

Scale 2½ inches to a mile.

Mechanical Engineers 1893.

Fig. 1. *Outside Elevation of Inverted Arc-Lamp.*



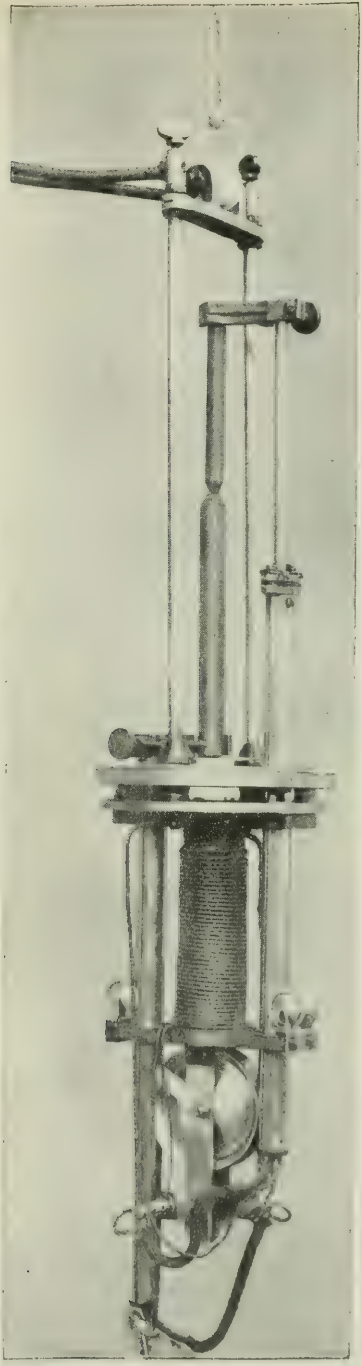


Fig. 2.
Elevation
of
Inverted
Arc-Lamp
with
Reflector
and Casing
removed.

Fig. 3. *Fluted Bottom-Rollers.*

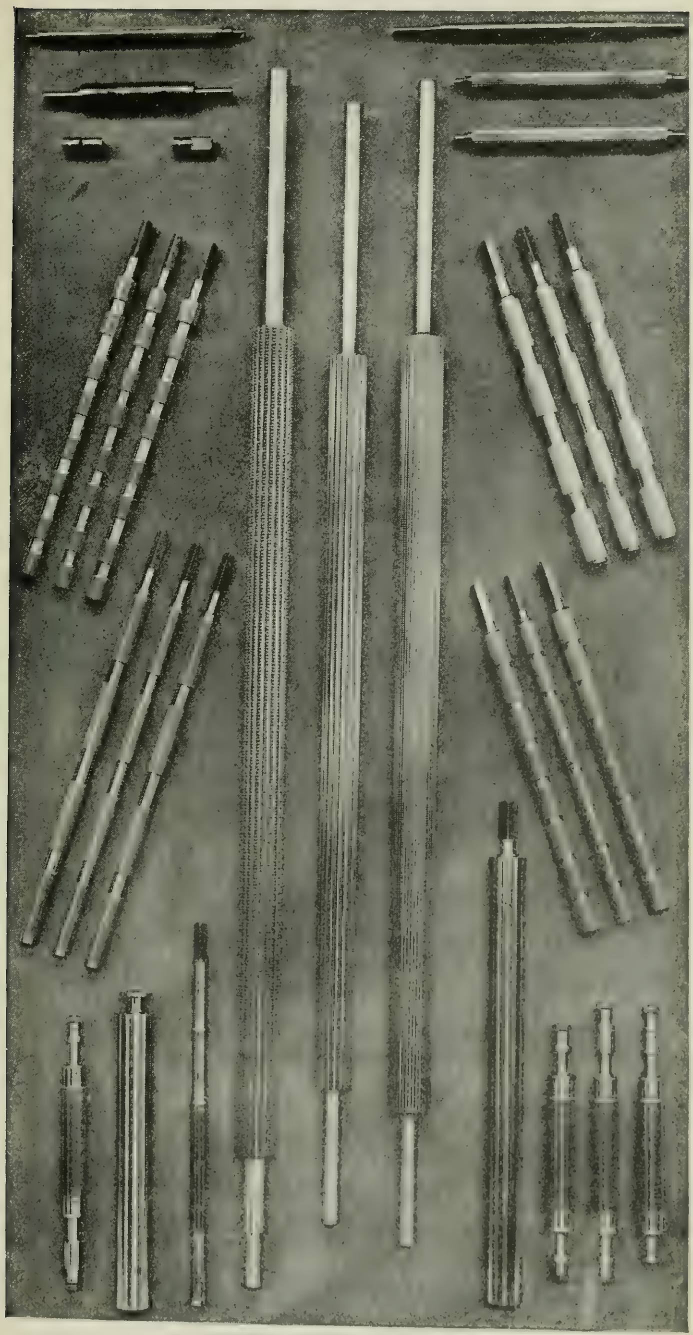
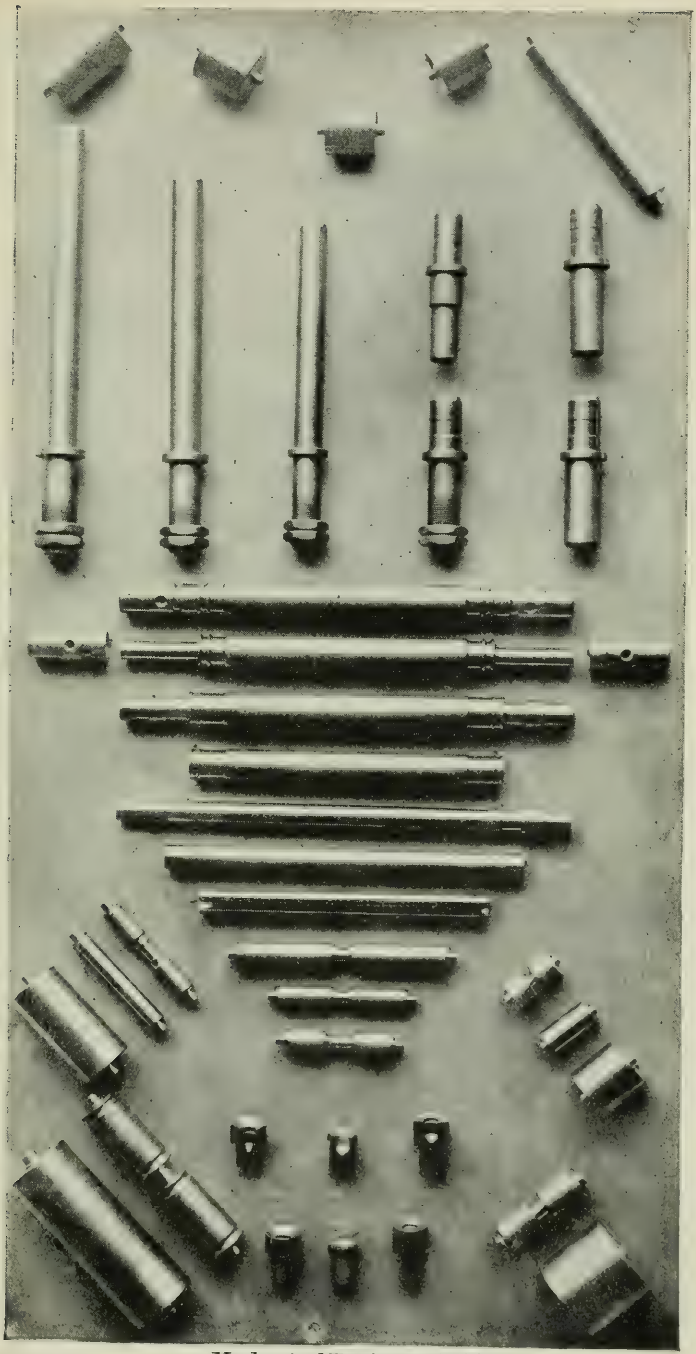


Fig. 4. *Top Rollers.*



Mechanical Engineers 1893.

Fig. 5. Flyers.

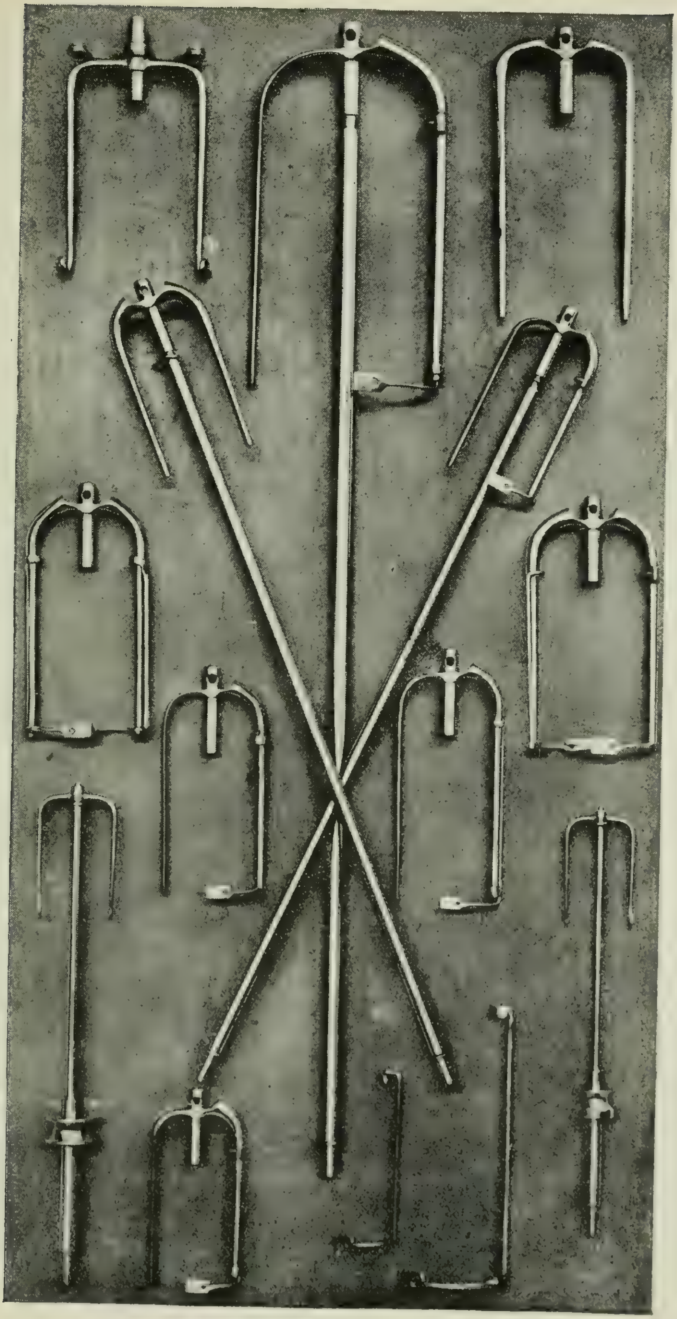


Fig. 6. *Bottom-Roller Room. Kay Street Works, Bolton.*

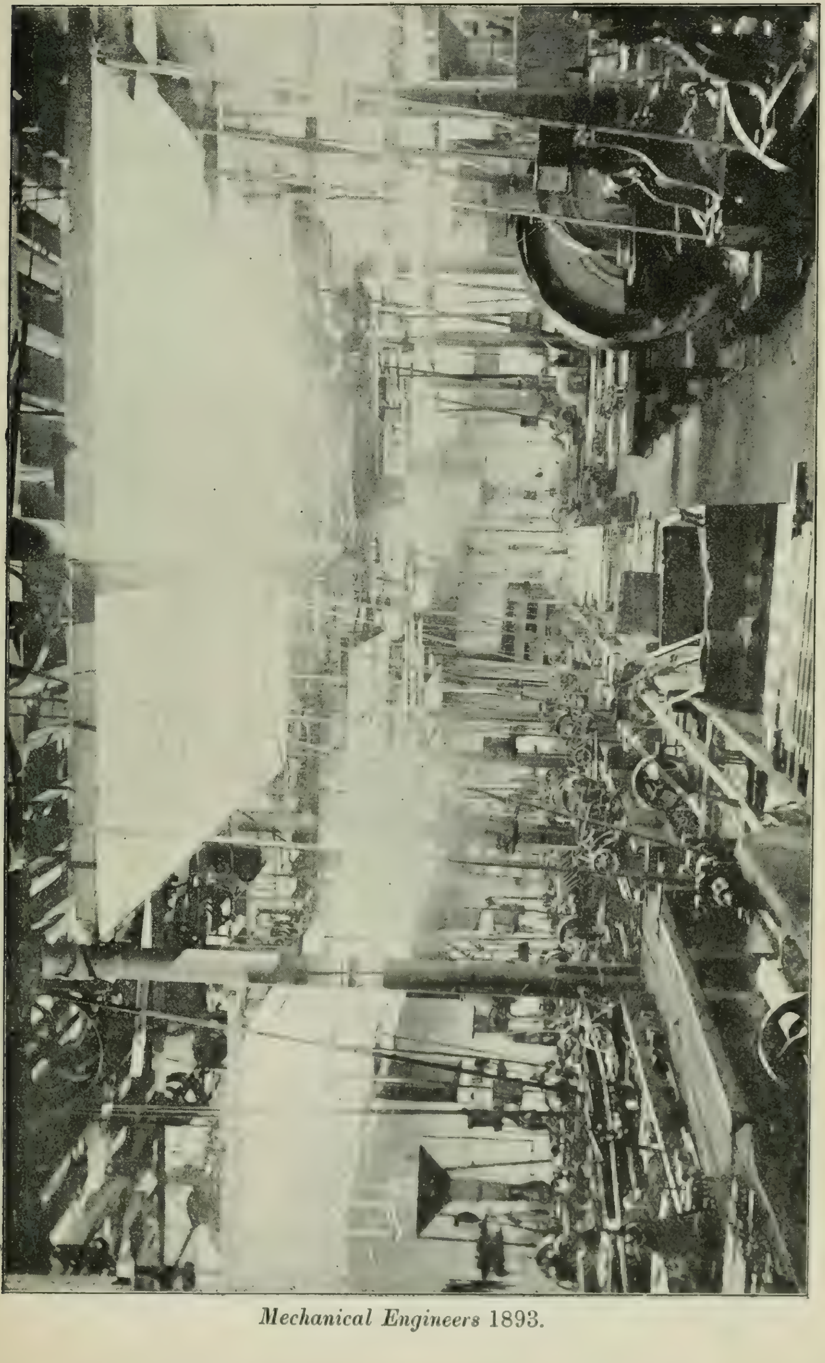
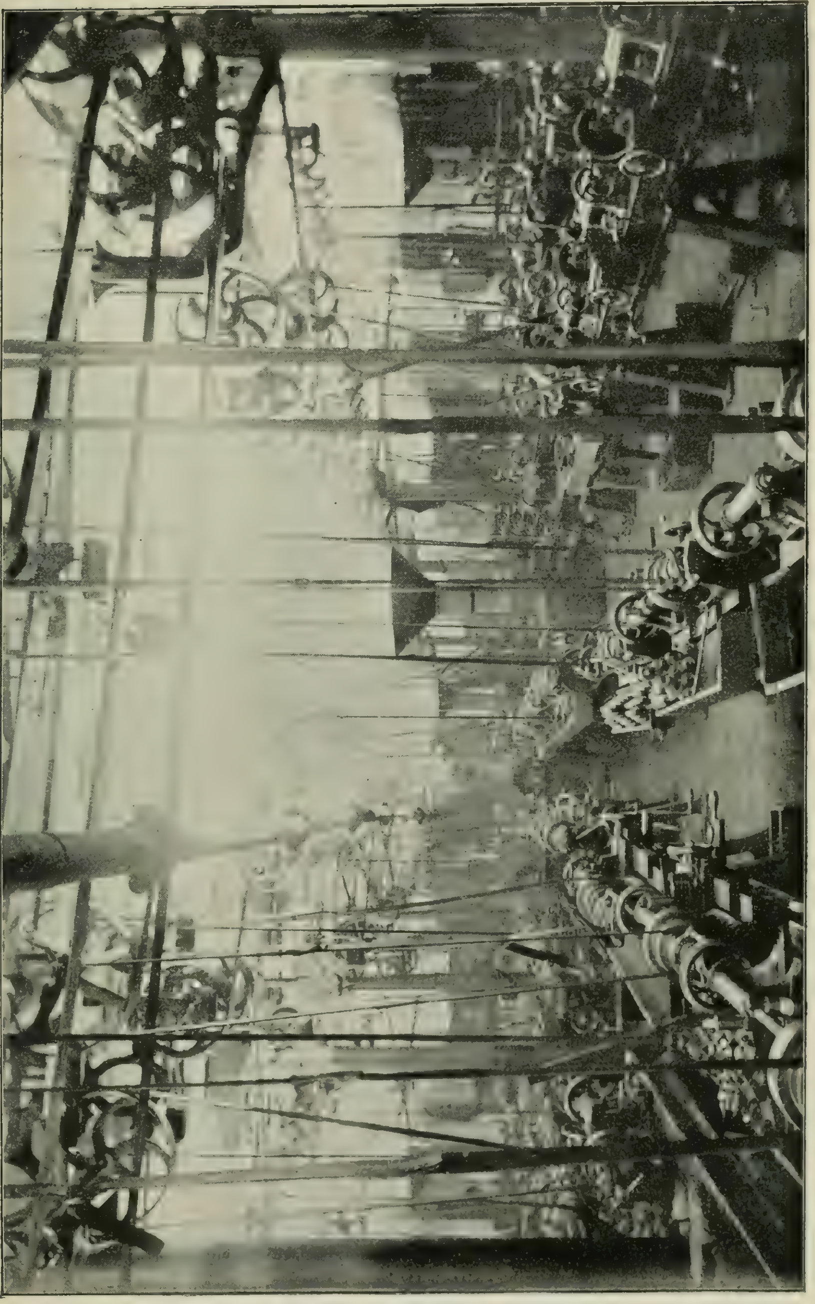


Fig. 7. *Top-Roller Room, Kay Street Works, Bolton.*



LIGHTING OF WORKSHOPS.

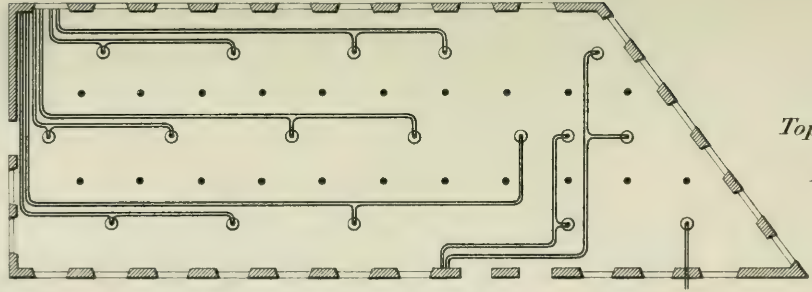
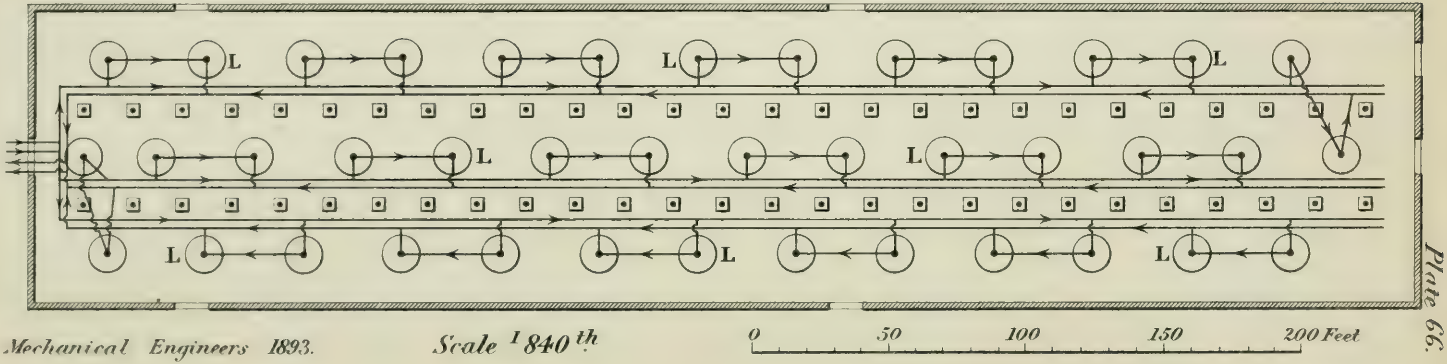


Fig. 8. *Plan of Top – Roller Room, Kay Street Works, Bolton.*

Scale 1/420th.

Fig. 9. *Plan of Machine Shop, Lancashire and Yorkshire Railway Works, Horwich.*



Scale 1/840th.

Plate 66.

LIGHTING OF WORKSHOPS.

Fig. 10. *Transverse Section of Machine Shop, Lancashire and Yorkshire Railway Works, Horwich.*

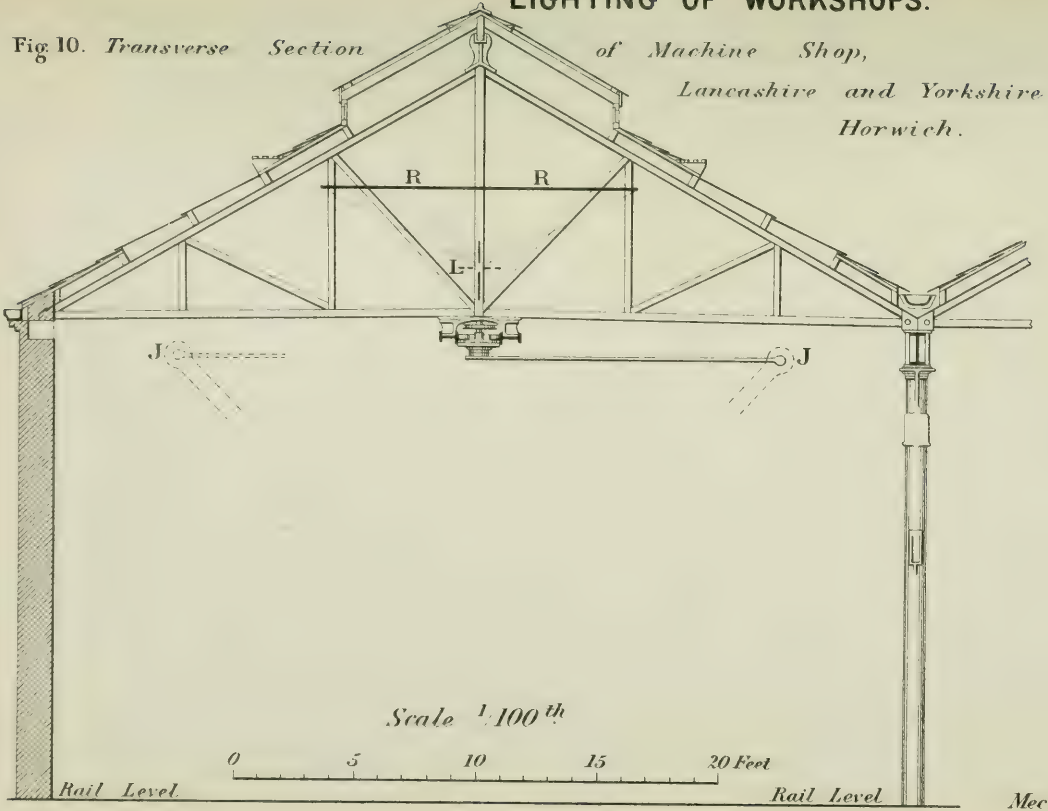
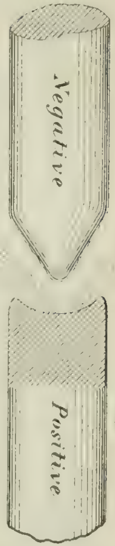


Fig. 11. *Carbons.*



Scale full size.

Fig. 12. *Fitting Shop,*

Lancashire and Yorkshire Railway Works, Horwich.

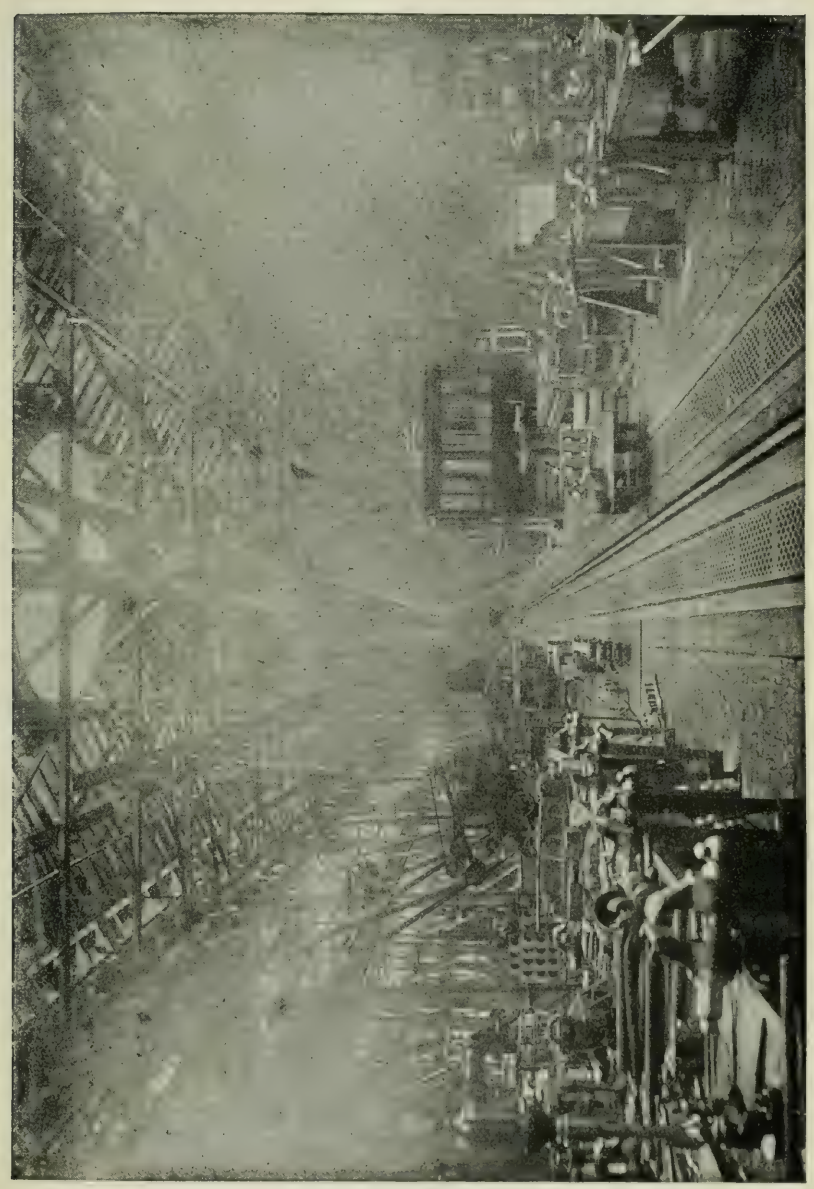
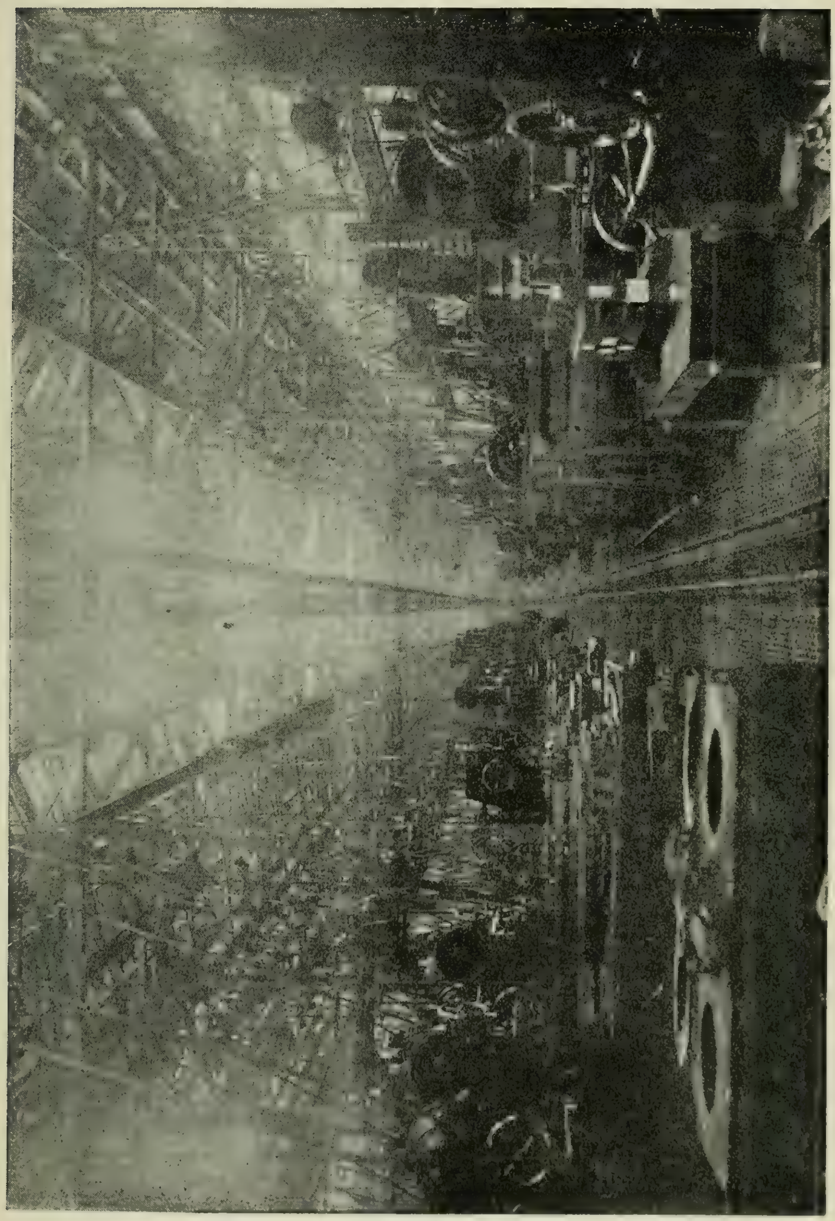


Fig. 13. *Fitting Shop,*
Lancashire and Yorkshire Railway Works, Horwich.



LIGHTING OF WORKSHOPS.

Automatic Switch. *Scale half size.*

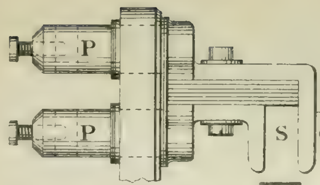


Fig. 17. *Plan of Contact.*

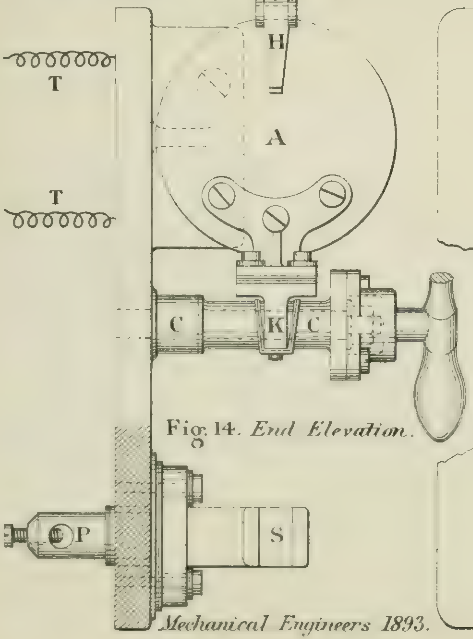


Fig. 14. *End Elevation.*

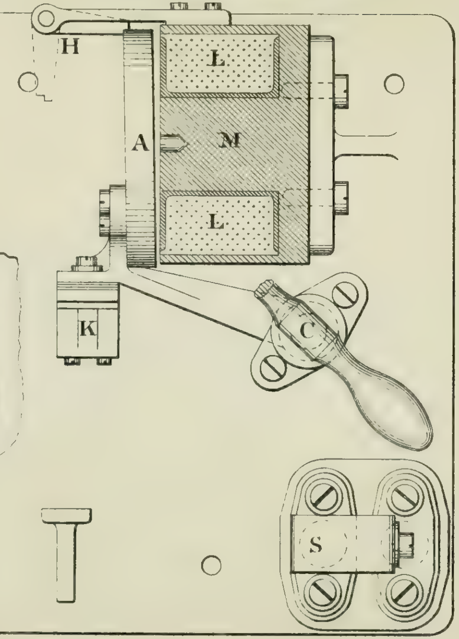


Fig. 15. *Switch open.*

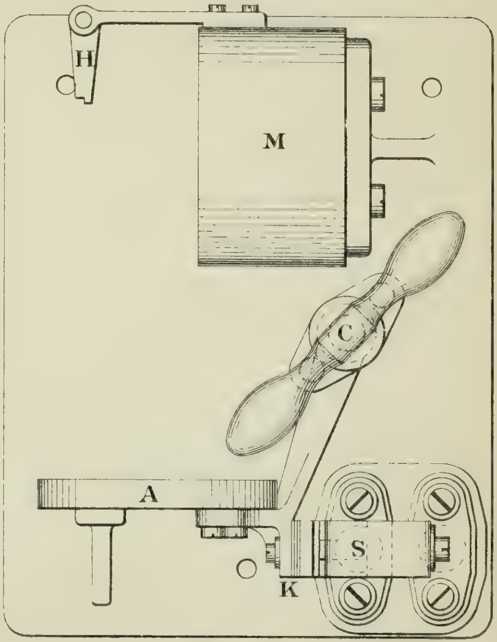


Fig. 16. *Switch closed.*

Mechanical Engineers 1893.

LIGHTING OF WORKSHOPS.

Oil-Vapour Flare-Lamps.

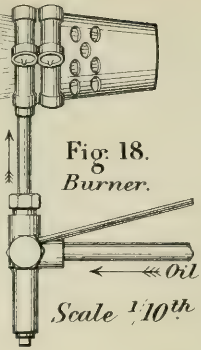


Fig. 18.
Burner.

Scale 1/10th.

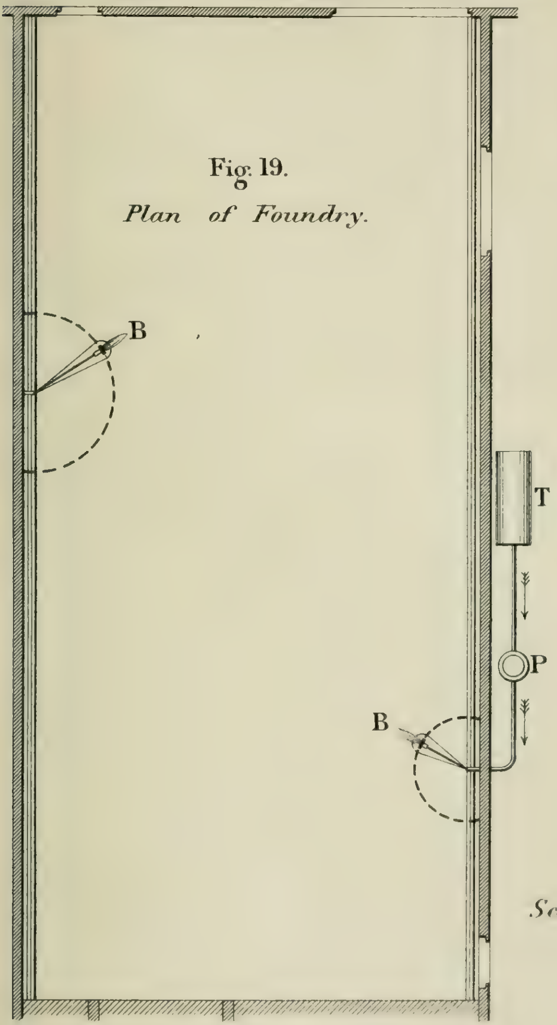


Fig. 19.
Plan of Foundry.

Scale 1/200th.

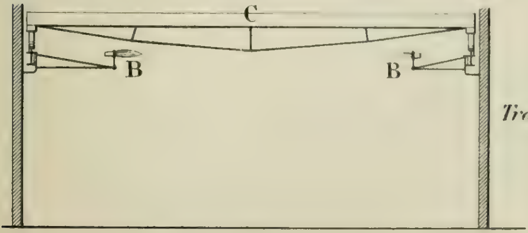


Fig. 20.
Transverse Section of Foundry.

Mechanical Engineers 1893.

WORKING OF STEAM PUMPS.

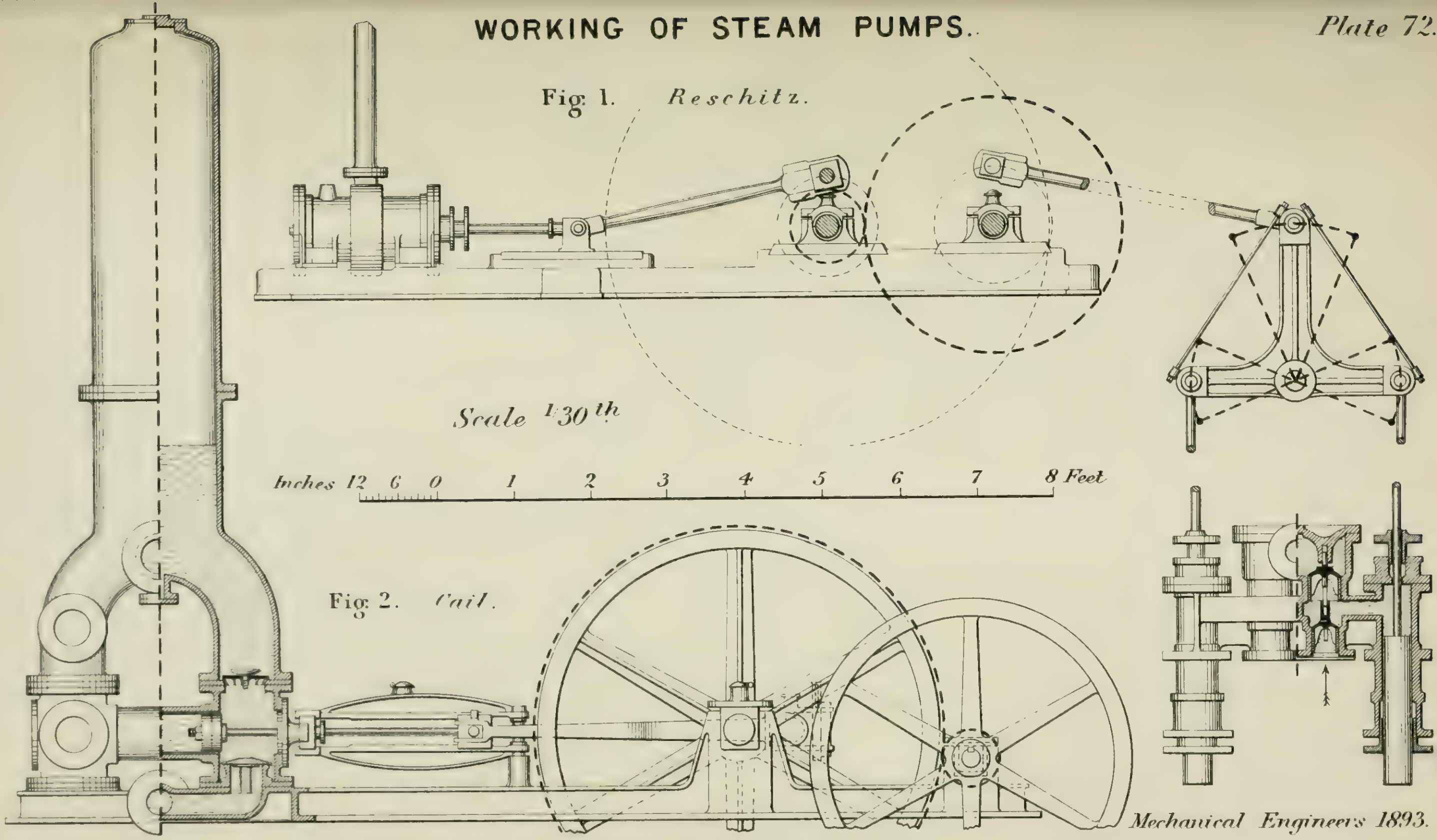


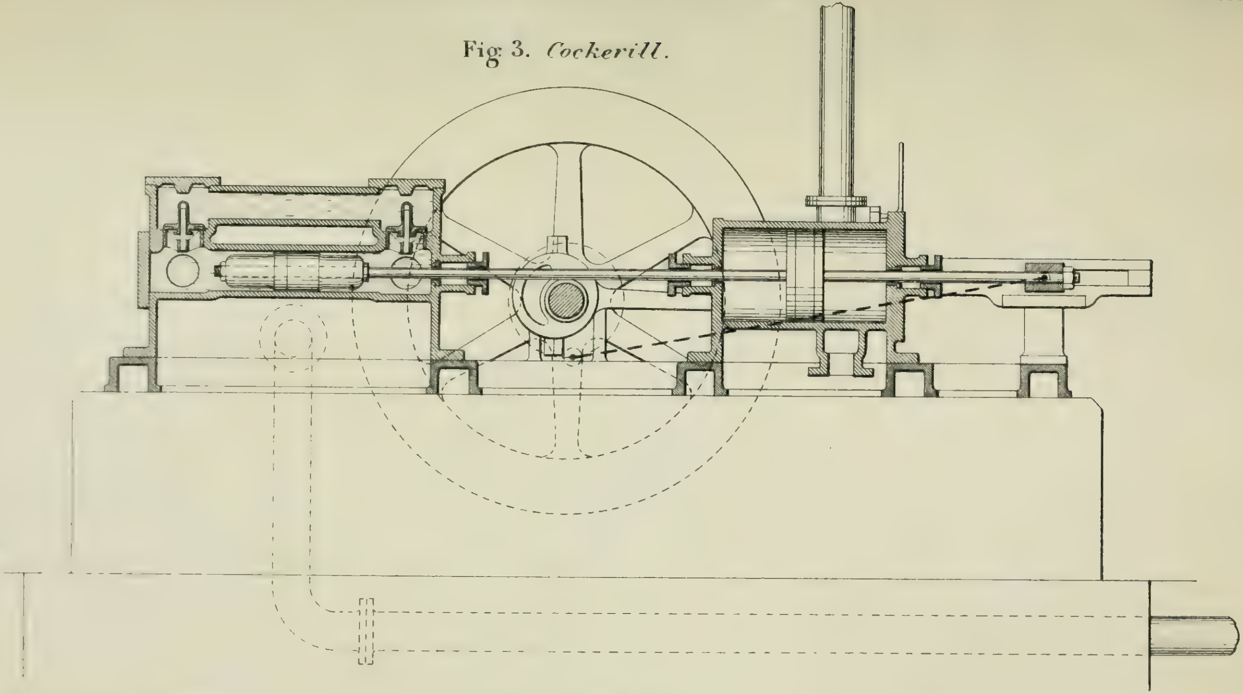
Fig. 1. Reschitz.

Fig. 2. Cail.

Scale 1/30th

WORKING OF STEAM PUMPS.

Fig 3. *Cockerill.*



Mechanical Engineers 1893.

Scale 1/20th

Inches 12 6 0 1 2 3 4 5 6 7 8 *Feet*

WORKING OF STEAM PUMPS.

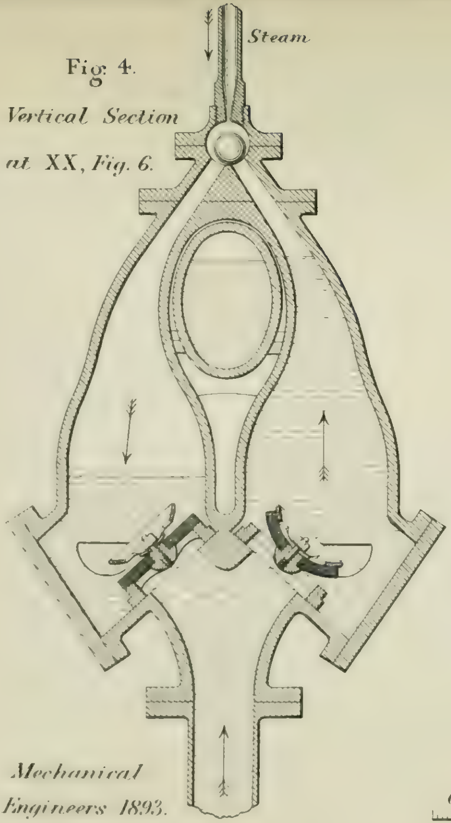


Fig: 4.
Vertical Section
at XX, Fig. 6.

Pulsometer.

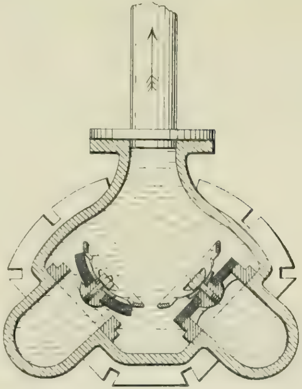


Fig: 5. Vertical Section
at YY, Fig. 6.

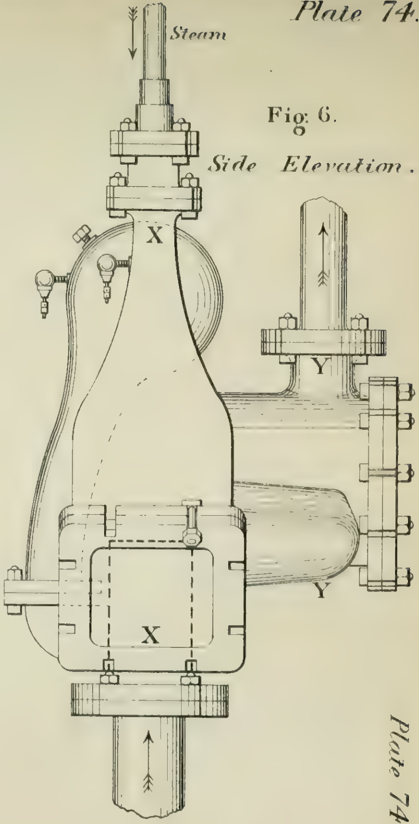


Fig: 6.
Side Elevation.

Scale 1/10th

0 5 10 15 20 Inches

Plate 74.

WORKING OF STEAM PUMPS.

Hayward Tyler.

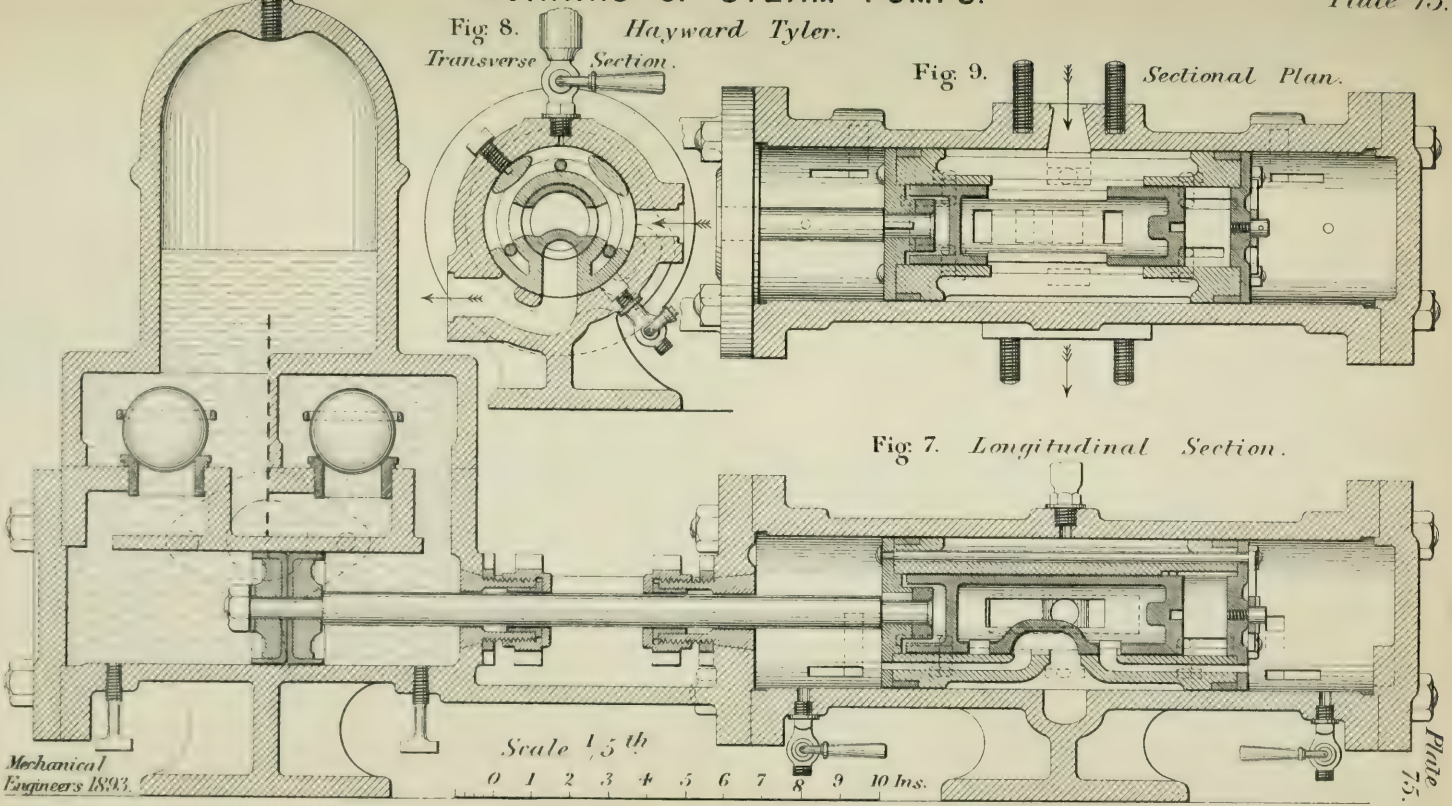


Fig: 8. Transverse Section.

Fig: 9. Sectional Plan.

Fig: 7. Longitudinal Section.

WORKING OF STEAM PUMPS.

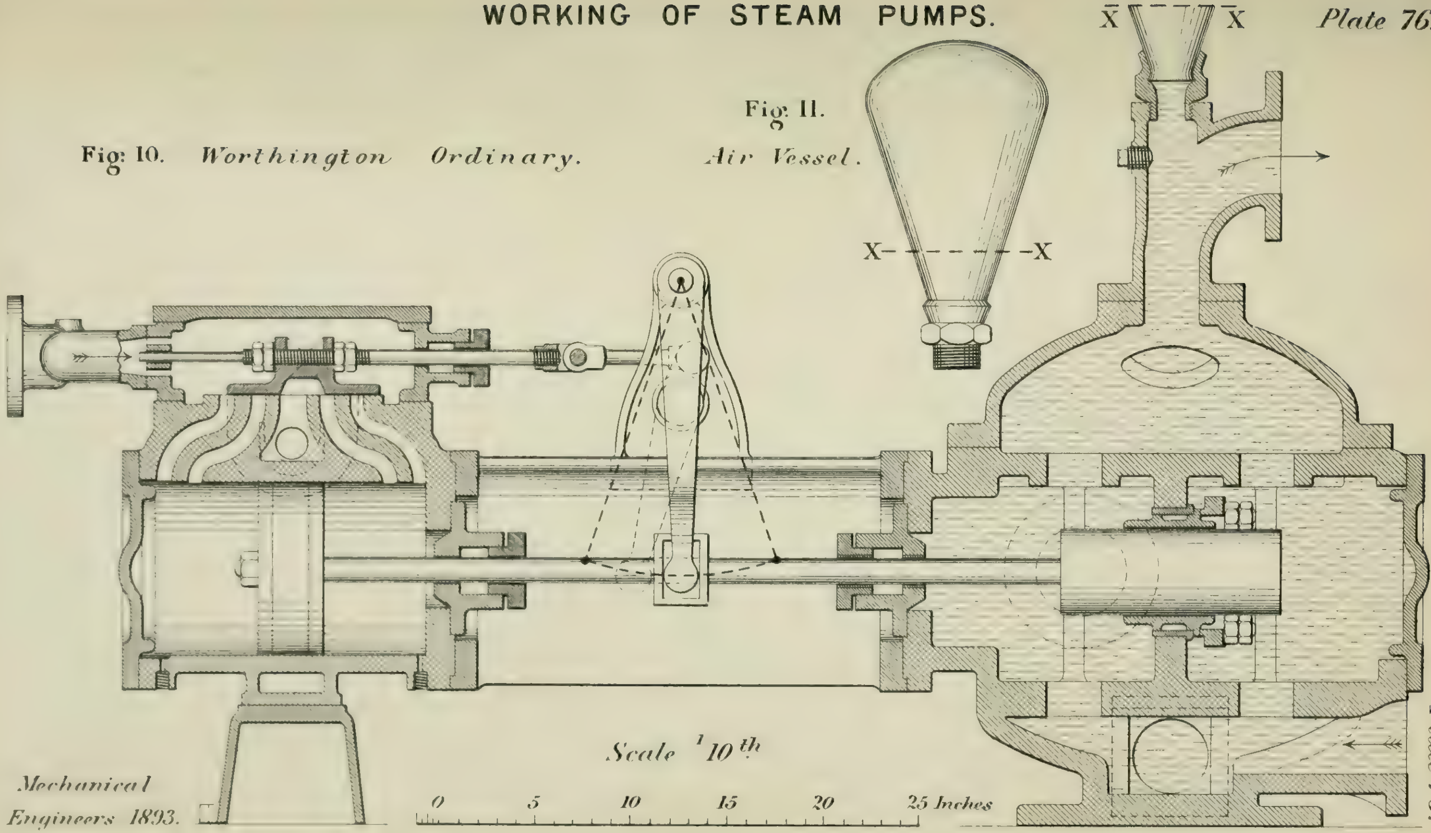


Fig. 10. *Worthington Ordinary.*

Fig. 11. *Air Vessel.*

Plate 76.

Fig. 12. *Worthington Compound.*

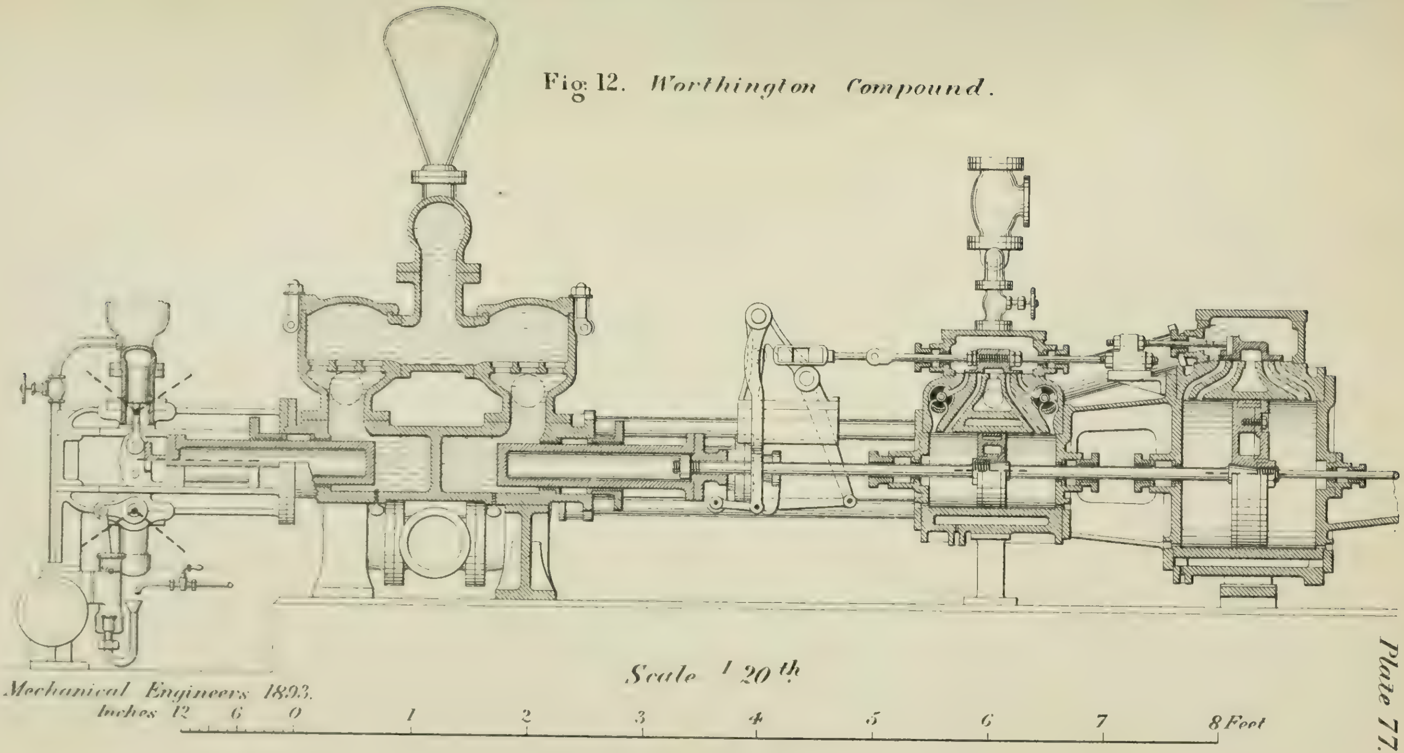
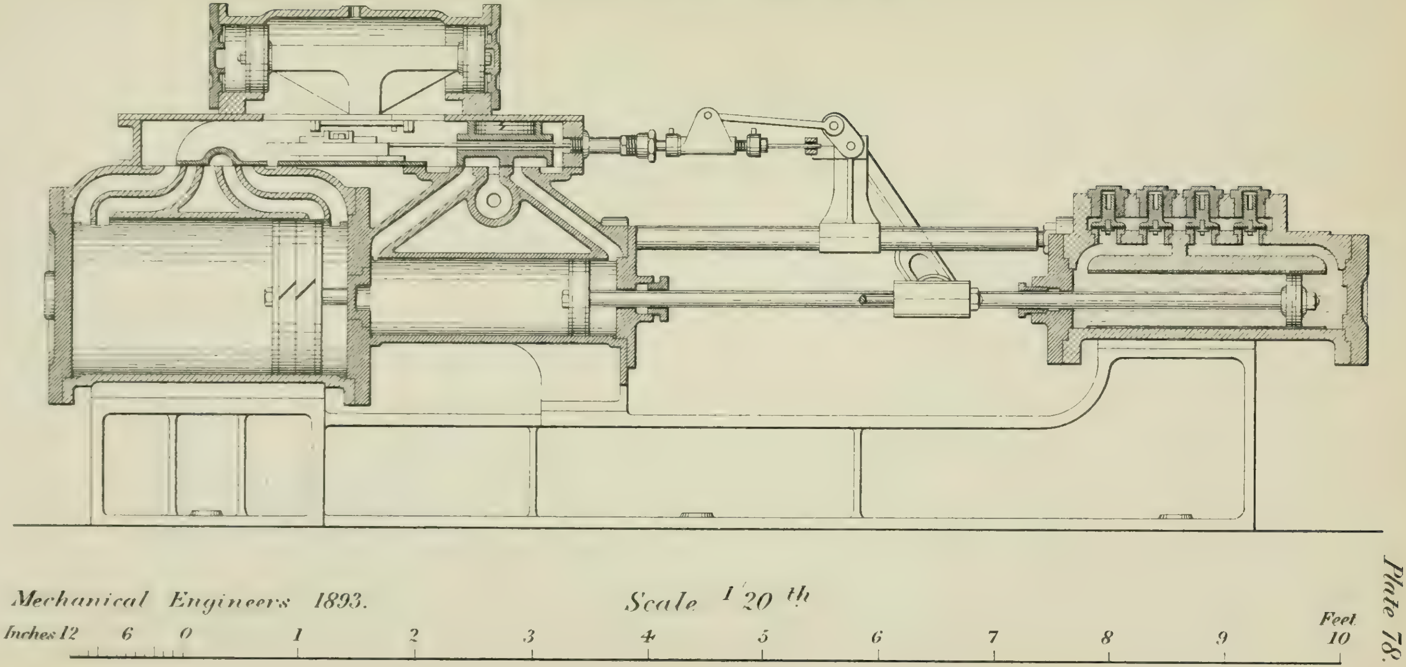


Plate 77.

WORKING OF STEAM PUMPS.

Fig. 13. *Blake Compound.*



Mechanical Engineers 1893.

Scale 1/20 th

WORKING OF STEAM PUMPS.

Indicator Diagrams from
Duplex Direct-acting Steam-Pump.

Boiler pressure 42 lbs.

Fig. 14. *Steam Cylinder.*

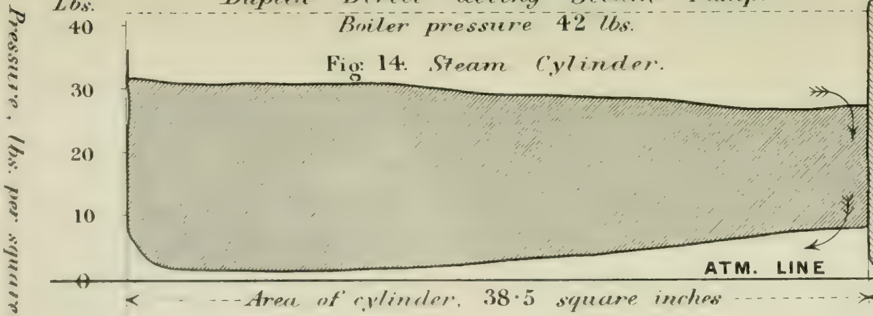
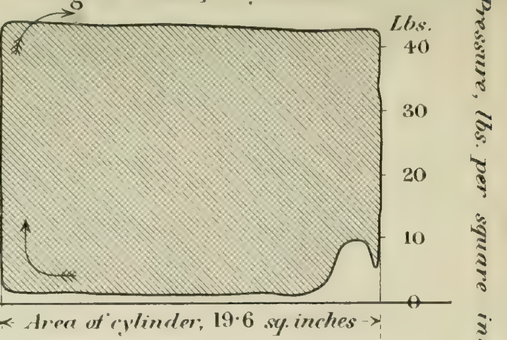


Fig. 15. *Pump Cylinder.*



Boiler pressure 45 lbs.

Fig. 16. *Steam Cylinder.*

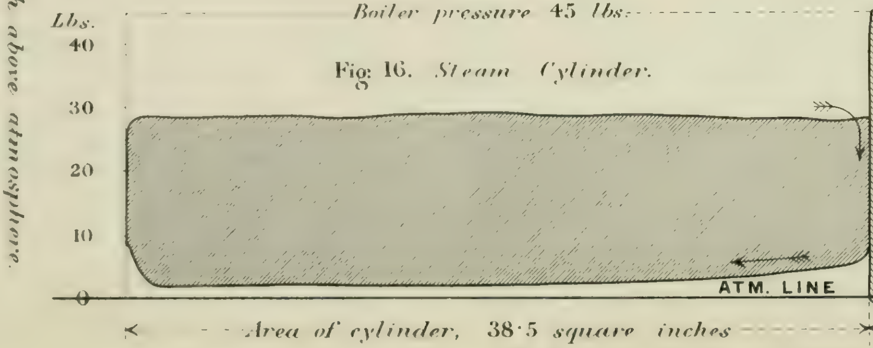
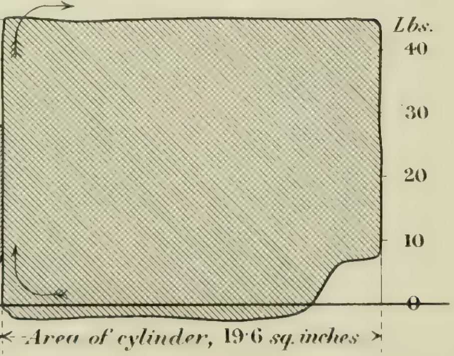


Fig. 17. *Pump Cylinder.*



Mechanical Engineers 1893.

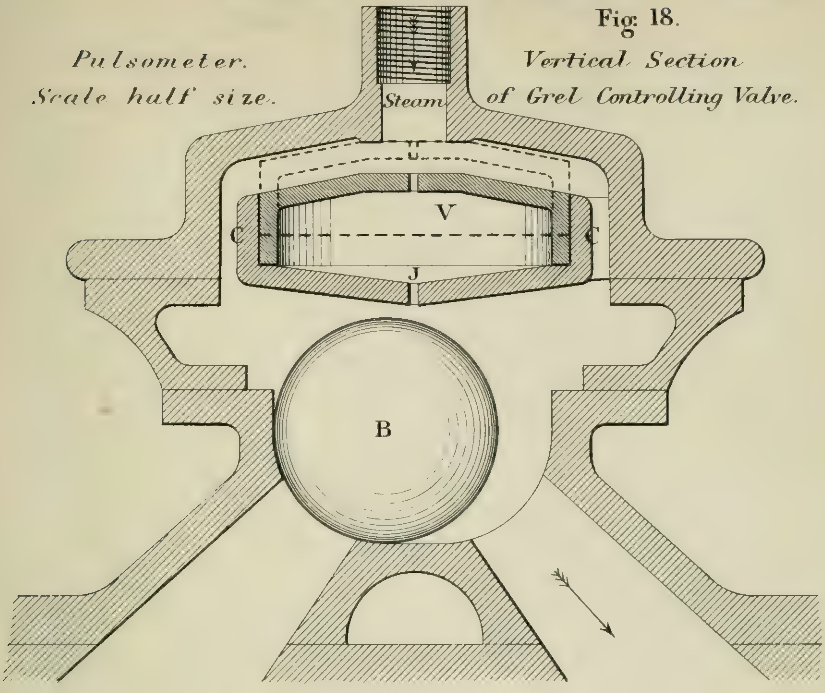


Fig: 18.

Pulsometer.
Scale half size.

Vertical Section
of Grel Controlling Valve.

Trial of Pulsometer.

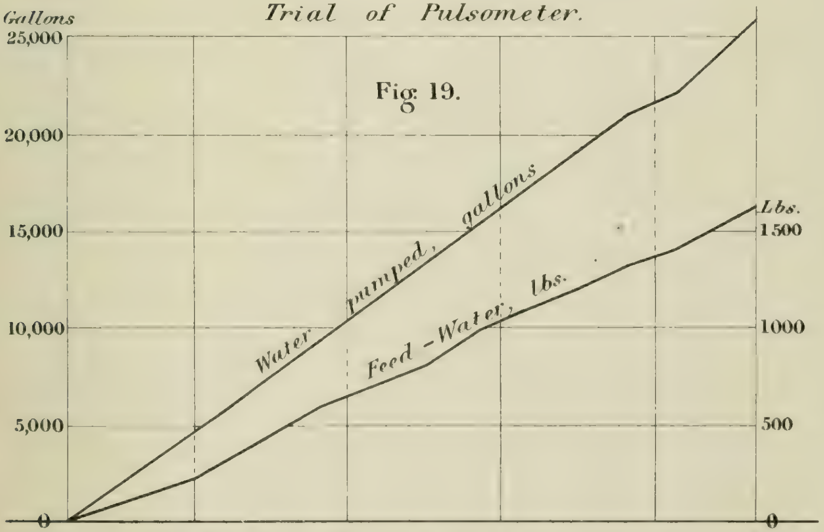


Fig: 19.

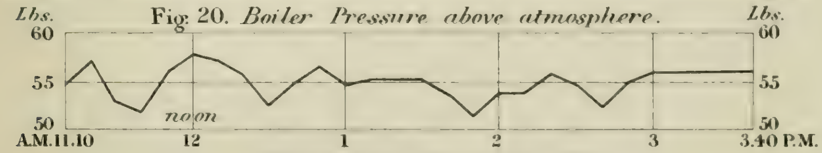
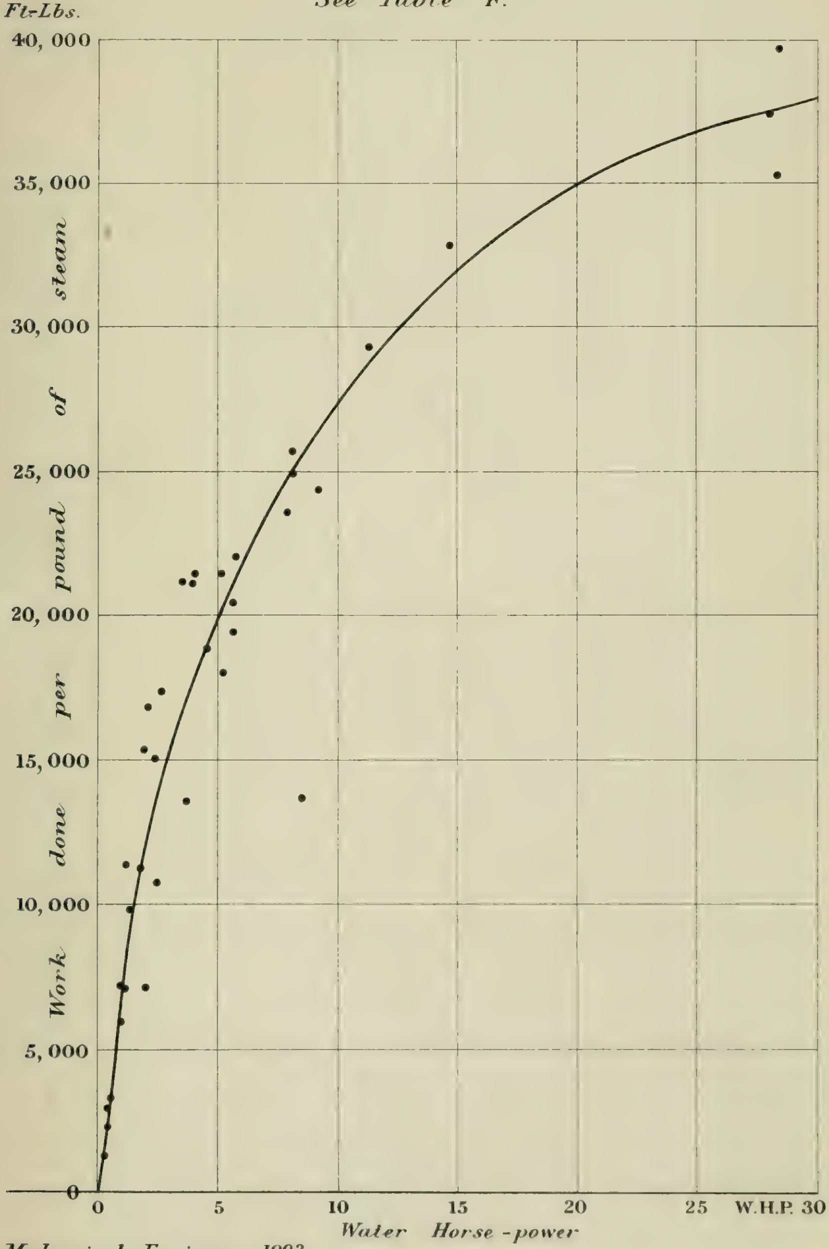


Fig: 20. *Boiler Pressure above atmosphere.*

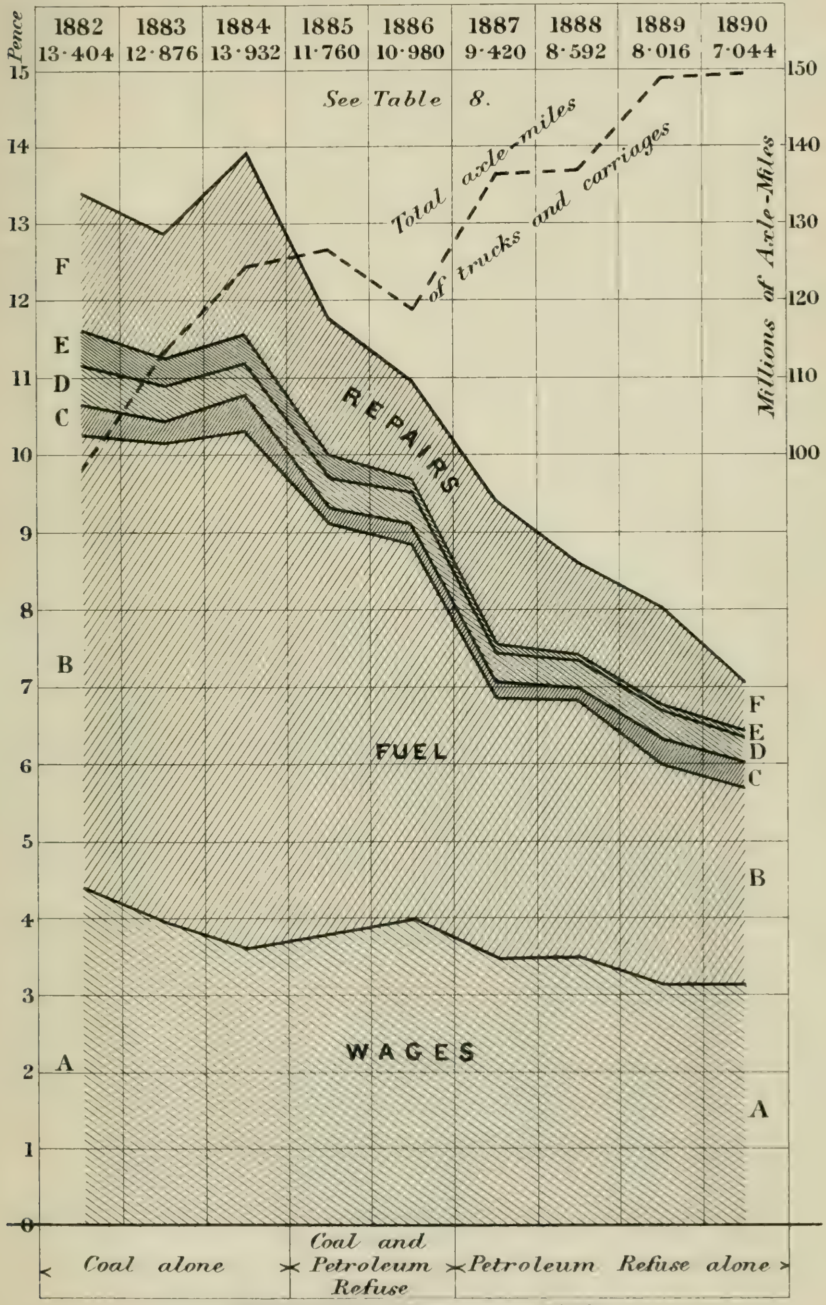
Water Horse-power, and Work done per pound of steam.

See Table 4.



WORKING OF STEAM PUMPS.

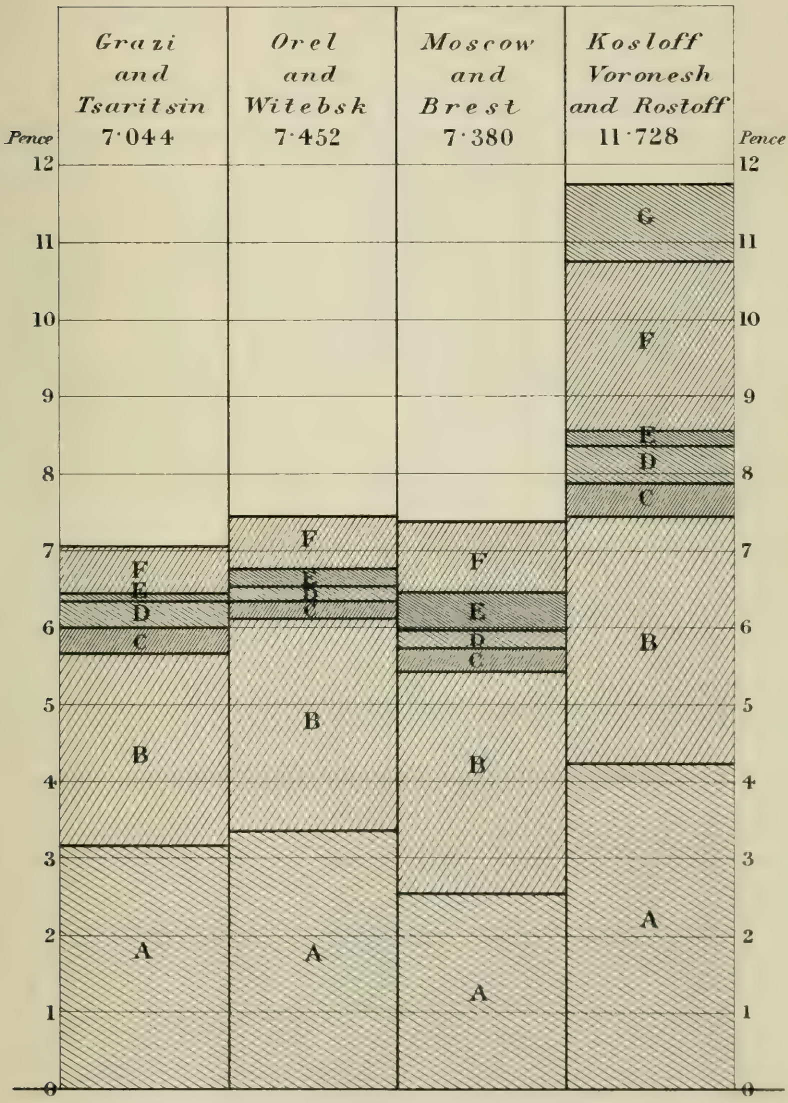
Cost of Water Supply
per thousand axle-miles of trucks and carriages
on the Grazi and Tsaritsin Railway during nine years 1882-90.



WORKING OF STEAM PUMPS. *Plate 83.*

Comparative Cost of Water Supply per thousand axle-miles of trucks and carriages on four Russian Railways in 1890.

See Table 9.



CYLINDER HEAT LOSSES.

Experimental Apparatus.

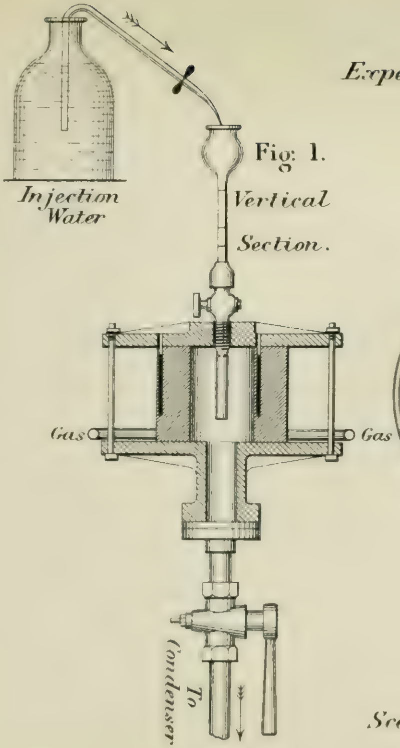


Fig: 1. *Vertical Section.*

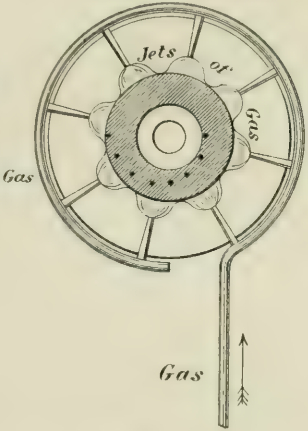


Fig. 2. *Sectional Plan.*

Scale $1/6$*th*

0 3 6 9 12 *Inches*

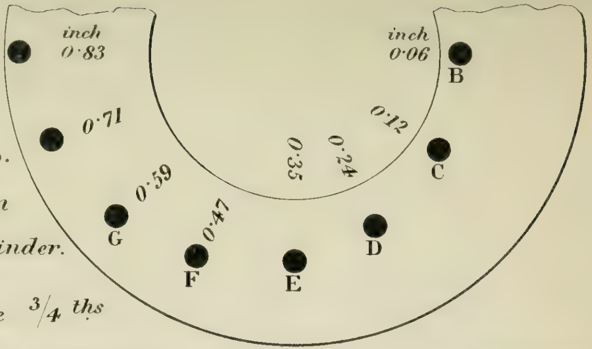


Fig: 3. *Plan of Cylinder.*

Scale $3/4$ *ths*

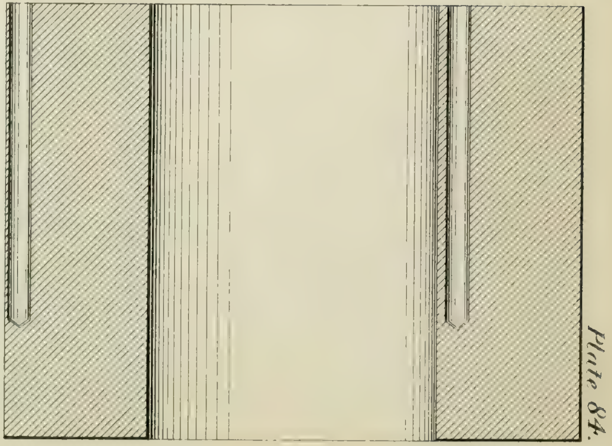


Fig: 4. *Vertical Section of Cylinder.*

CYLINDER HEAT LOSSES.

Range of Temperature in Hot Cylinder Walls exposed internally to water injection and vacuum.

Fig. 5.

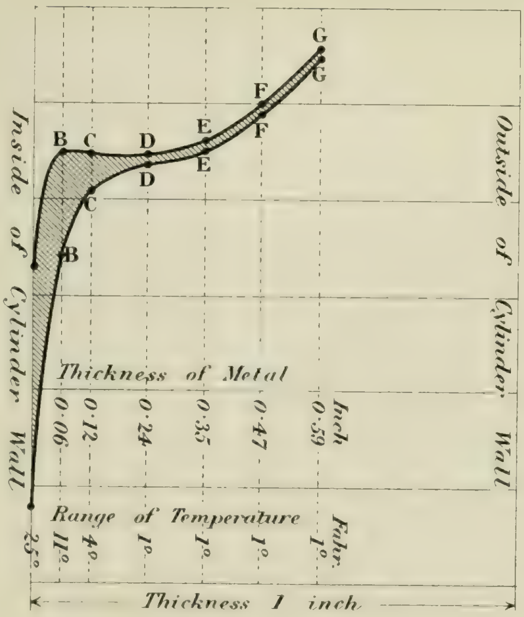
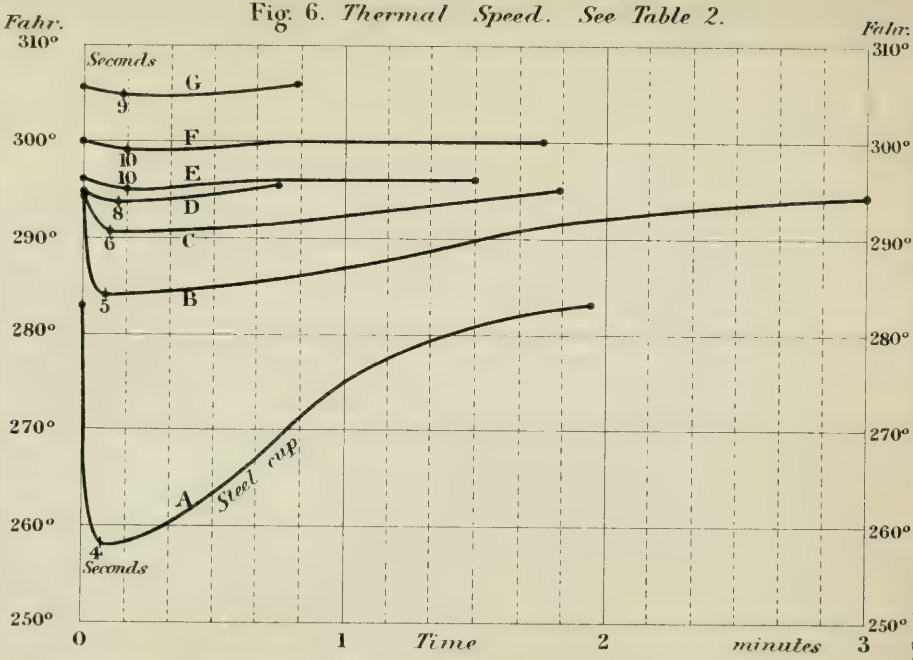


Fig. 6. *Thermal Speed. See Table 2.*



Mechanical Engineers 1893.

CYLINDER HEAT LOSSES.

Range of Temperature in Hot Cylinder Walls exposed internally to water injection and vacuum.

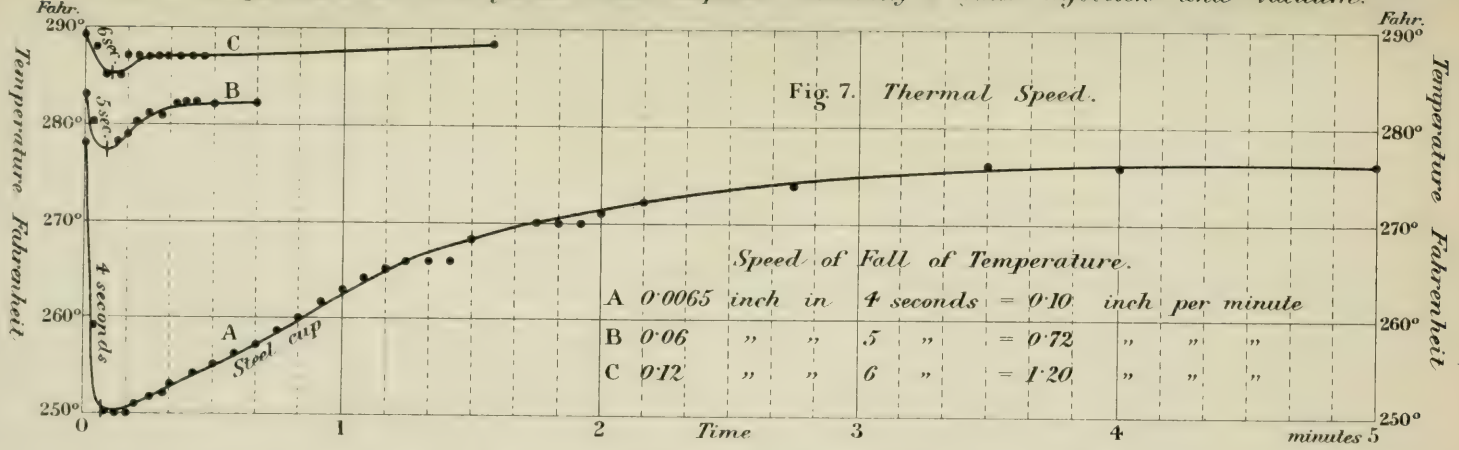


Fig. 7. *Thermal Speed.*

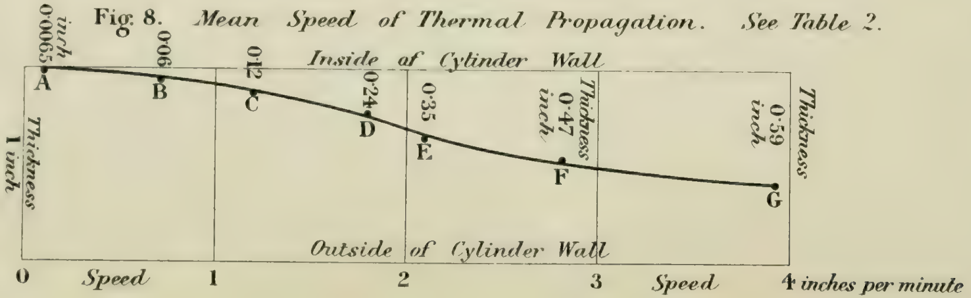


Fig. 8. *Mean Speed of Thermal Propagation. See Table 2.*

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